PHYSIOGRAPHY FOR BEGINNERS

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BY

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PREFACE

In the Forty-Second Report of the Department of Science and Art, the Director for Science, Captain W. de W. Abney, remarks :—

"The syllabus in Physiography has been thoroughly revised. It has now been so framed that it is, particularly in the Elementary Stage, a real introduction to the various branches of Physical Science, and can be taught in this stage without Mathematics. . . . One object of this revision has been to adapt it for pupil-teachers who may be called upon to give object lessons in their future career. Object lessons without a knowledge of the fundamental principles of Science must fall far short of what they should be, and are then worse than useless."

Under the guidance, and in the spirit of this new syllabus, an attempt has been made in this little book to provide the beginner with such an introduction to Physical Science. No knowledge of Mathematics, except an acquaintance with the ordinary processes of Arithmetic, has been assumed.

The lessons have been made as experimental as possible. Not only have the experiments accompanying the syllabus in the recent Science and Art Directory been incorporated, but many others have been added. Those from the Directory are indicated thus, §.

Teachers are strongly urged to perform the experiments before their classes, and not, as is unfortunately so often the case, content themselves with telling the students to read about the instructions and exercise their imaginations. The latter proceeding is no substitute for the former.

The author is unaware of the existence of any other elementary book on the subject, aiming at the Science and Art examination as a proximate end, which contains any instructions for simply arranged experiments needing comparatively little apparatus, such as are here given, and he trusts that the tentative arrangement, made with the help of the Directory, may provide to some extent this greatly needed factor.

The particular requirements of the pupil-teacher, to which Captain Abney calls attention, have been borne in mind throughout, and no difficulty should be experienced in devising numerous object lessons with the assistance of the experiments here given.

The summaries at the ends of the chapters are designed to supersede most of the dictation practised in evening classes, and so leave the teacher ampler time to experiment, exhibit, and explain—his proper function.

In writing the sections on Heat, Light, and Sound, a free use of the companion book in this series, by Mr. D. E. Jones, has been made; while a cursory glance at the astronomical chapters will show my indebtedness to "The Planet Earth," by Mr. R. A. Gregory. The pages on the work of Rivers and Glaciers have been modelled on the plan of Sir A. Geikie's "Text Book of Geology."

Although my name alone appears upon the title-page of this book, much of the arrangement and several sections therein are the work of Mr. R. A. Gregory, whose name will be familiar to every student of physiography in this country. I have to thank him too for advice in the selection and construction of the figures, and for revising the book thoroughly for the press. Whatever merits the book possesses, must in common fairness be ascribed rather to him than to me. I wish I could father its defects upon him with as certain a mind.

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CONTENTS

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CHAPTER I

MATTER

Matter.—Our earliest knowledge of the world teaches us that on every side we have what we familiarly speak of as *things* of all kinds. We become aware of the existence of these things in different ways. Some we feel, some we smell, some we see, some we taste, while others again make their existence known to us by the sounds we hear. On a windy day at the sea-side, standing on the beach, we feel the ground under our feet; we smell, it may be, the tar on a neighbouring boat or the sea-weed on the shingle; we see a distant ship at sea or the clouds hurrying across the sky; we taste the salt in the air; and we hear the never-ceasing roar of the waves as they break in at our feet. All these things, about which we get to know by our senses, are called *material* things; they are forms of *matter*. We must think of matter, then, as meaning *all things which exist in or out of our world, which we can become aware of by the help of our senses.*

Of course the number of different kinds of things is innumerable, but yet they can all be arranged in three classes, according to certain of the properties they possess and which we shall immediately have to study. The classes are (1) *Solid things or solids*; (2) *Liquid things or liquids*; (3) *Gaseous things or gases.* Sometimes the last two are made into one class and called *fluids.*

Properties possessed by all forms of Matter.—We shall have occasion to use the word *properties* so often that it will be well to clearly understand what meaning the word conveys, and this can be best obtained by one or two examples. We say a strawberry is sweet, or a strawberry has the property of sweetness; the paper of the book is white, or the paper possesses the property of whiteness; the sun is bright, or the sun is noted for the property of brightness. Evidently, then, "*properties are certain effects caused by the things which are said to possess them.*"

There are certain properties possessed in common by all forms of matter; these are said to be *general properties. Matter must occupy a certain space*, or possesses *extension;* the larger it is the larger the space occupied by it. It will further be obvious to every one that two material things cannot occupy the same space at the same time. This property is expressed by saying that matter is *impenetrable.* Matter, too, *offers resistance.* We become aware of this, in the case of solids, if we knock ourselves against the wall or the table; if we swim or wade in water we know the same thing is true of water, and so we find it to be of all liquids; if we attempt to run with a screen in front of us we become conscious of the resistance by the air to our onward progress, and from this argue that gases, too, offer resistance.

Matter has Weight.—Without knowing the full significance of the expression *weight*, we shall have a sufficiently clear idea of what is meant by this property from its familiar use in everyday conversation. By lifting a solid we become conscious of its possession of this property; if we lift an empty bottle and then one full of any liquid, we shall find it is lighter in the first instance, or, as we say, the liquid has weight. By the exercise of sufficient care, in just the same manner it can be shown that gases have weight.

If we throw a stick at a cocoa-nut at a fair, or send a jet of water at a ball, or blow at a piece of paper, another of the general properties of matter can be demonstrated, namely, the power of giving motion to other things by striking against them. To sum up, "*Matter occupies space, offers resistance, possesses weight, and transfers motion to other things when it strikes against them.*"

Other Properties of Matter.—Matter possesses other characters or properties which it will be useful for us to study. Though these are general properties, it is possible to form a good elementary conception of matter without taking them into account, and it must be remembered that some of these properties cannot be universally applied to every condition of matter. We shall consider (1) Divisibility, (2) Porosity, (3) Compressibility, (4) Elasticity, (5) Inertia.

Divisibility.—Imagine some material body before you on a table. You know that with suitable means you can divide it into parts by cutting, that each of the halves can be again divided, and that the bisection can be continued as long as the knife is sufficiently fine and sharp to be able to cut the substance. Evidently, if you could only get sharper and sharper knives, and keener and keener eyes, this process of division could be carried on for a very long time. This property is what is understood by *divisibility*. The question will probably present itself to the reader, Could this division go on for ever; is divisibility indefinite? There are reasons for believing that it is not, you could not go on dividing indefinitely; by and by extremely minute and indivisible parts would be reached, called *atoms*. It must be at once understood that atoms have never been seen. We can only imagine what would be the end of our process of division. Our strongest microscopes bring us nowhere near the power necessary to bring an atom into the scope of our vision.

Porosity.—We are all in the habit of associating this property with certain familiar forms of matter. The sponge we use in the bath has holes through it, or is, as we say, *porous*; the substances used in filters must also evidently be porous, or else the water would not percolate through them. Porosity refers to the possesssion of these *interstices* or *pores*. In some cases, though we cannot see these pores with the naked eye, we easily perceive them with a microscope. The pores have often been shown to exist, even where it is difficult to imagine their existence, by forcing water through them. Thus Francis Bacon, in 1640, forced water through a very carefully closed sphere made of lead.

Expt. 1.—Procure a piece of chamois leather; make it into a bag, and pour some mercury into it. Increase the pressure on the mercury

by twisting the leather. The mercury is forced through the pores. This is the common way of filtering mercury.

EXPT. 2.—Half fill a barometer tube with water; then gently add alcohol until the tube is nearly full. Make a mark on the tube at the level with the top of the liquid column, and afterwards shake the tube so as to mix the water and alcohol well together. Observe that the volume of the mixture has diminished, the reason being that some of the water has filled up pores between the particles of alcohol.

Compressibility.—This power follows as a natural consequence of that just described. If pores exist between the indivisible small particles of which matter is built up, it ought to be possible, by the adoption of suitable means, to make these particles go closer together. This is found to be the case. By pressing upon the body from outside it can be made smaller.

This is very notoriously the case in gases, they can actually be made to become successively one-half, one-quarter, one-eighth, and so on up to at least one-hundredth of their original size. The same thing holds true in the case of solids, though to a much smaller extent. A familiar example of the compression of solids is seen when a druggist presses a cork between two pieces of iron in order to make it fit a bottle for which it was previously too large. But generally in the case of solids the pressure exerted has to be very great to bring about quite a small compression.

It was believed for a long time that liquids could not be compressed, but it is now known that they can be very slightly reduced in volume, that is, the particles can be forced nearer together.

Thus we learn that *compressibility is not only a consequence of porosity but actually a proof of its existence.*

Elasticity.—Imagine a gas to have been made to assume one-half its size by compressing it. What would happen if the pressure which is the cause of the diminution were suddenly removed? The gas would resume its original size or volume, and it would, so far as appearances are concerned, seem to have undergone no change. The gas is said to be perfectly *elastic*, and the property which enabled it to go back to its original state is called *elasticity*. Similar results follow with liquids; they also are perfectly elastic.

Some differences arise when solids come to be examined. Though the property can be developed in solids in at least four ways—by *pressure*, by *pulling*, by *bending*, and by *twisting*—we need only in this connection consider the first, as it is the elasticity which is developed by pressure which is most marked in all forms of matter. Ivory, marble,

and glass are examples of elastic solids ; while clays, fats, and even lead are instances of solids with scarcely any elasticity.

A solid will only resume its former dimensions when the pressure is removed, provided that the pressure is within a certain limit. If the pressure be more than this minimum amount, or if it exceeds the *limit of elasticity*, as it is called, the solid will not return to the initial size ; it will undergo a permanent change.

EXPT. 3.—Procure a slab of polished marble or some similar material and smear it with oil. Drop a billiard ball or a large glass marble from a considerable height on to the slab. Catch it as it rebounds. Notice that a blot of oil is found where the ball came into contact with the slab. Compare the size of the blot with the spot which is formed when the marble is placed in contact with the slab.

Evidently the ball underwent a compression as the result of collision with the slab, and, by virtue of its elasticity, it regained its original size, causing the rebound.

Inertia.—This property will be considered more fully in a later chapter, and we will let it suffice to say here that it is entirely a negative property. All matter at rest will remain so until acted upon by some force, and all matter in motion will continue moving in the same direction until made to change its motion by some force acting upon it.

Solids, Liquids, Gases.—The fact that there are three kinds of material things has been stated as being one of common knowledge. We must add to this another idea, viz., that *matter can exist in three different states.*

§ EXPT. 4.—Procure a lump of ice and notice that it has a particular shape of its own, which as long as the day is sufficiently cold, remains fixed ; it is also hard. With a sharp brad-awl or the point of a knife break it up into pieces, and put a convenient quantity of them into a beaker. Place the beaker in a warm room, or apply heat from a laboratory burner or spirit lamp. The ice disappears, and its place is taken by what we call water. Notice the characters of the water. It has no definite shape, for by tilting the beaker the water can be made to flow about. Neither is the water hard. Replace the beaker over the burner and go on warming it. Soon the water boils, and is converted into vapour, which spreads itself throughout the air in the room, and seems to disappear. The vapour can only be made visible by blowing cold air at it, when it becomes white and visible, but is really no longer vapour, but has condensed into small drops of water.

Here the same form of matter has been made to assume three states ; in other words, ice, water, and steam are the same form of matter in the solid, liquid, and gaseous state respectively.

The transition from one state to another may be sudden or gradual.

EXPT. 5.—Warm a Florence flask by twirling it between the finger and thumb above the flame of a laboratory burner. When it is too warm to bear the finger upon the bottom, introduce a crystal of iodine, and notice it is at once converted into a beautiful violet vapour. It seems to suddenly pass from the condition of a solid to that of a vapour.

§ EXPT. 6.—Suspend a stick of sealing-wax horizontally between two pins suitably fixed in uprights, and notice that in the course of an hour or two it becomes bent downwards in the middle. It has gradually flowed. Now warm a lump of sealing-wax in an iron spoon, and notice the gradual conversion into a liquid. Refer back to this experiment when reading the section on Viscosity, p. 10.

What, then, are the distinctive properties of these three forms of matter? We will consider them in order.

Distinctive Characters of Solids.—A solid body does not readily alter its size or shape. It will keep its own volume and the same form unless subjected to a considerable force. It has been already shown that elasticity can be called into play in solids by pressure, and we have now to prove that it is also called into play by pulling, bending, or twisting.

It would take us farther into the subject of Physics than we can afford space for to describe how the elasticity has been measured in these cases, but that there is an alteration of form when solids are treated in these ways can be easily shown.

EXPT. 7.—Fix one end of a piece of indiarubber cord, or tubing, about two feet long, to a support. Stick two pins through this cord about 18 inches apart. Tie the lower end of the cord into a loop, and then hang a weight by means of a hook from it. Measure the distance between the pins before and after putting on the weight. Repeat the experiment with different weights. You will notice that the cord can be stretched or elongated, because the weights exert a pulling force upon it. If a long metal wire is used instead of the cord, the stretching can be measured in a similar way, but it is much less; for instance, a brass wire $\frac{1}{25}$ inch in diameter and eleven feet long elongates about $\frac{3}{25}$ inch when a weight of 28 lbs. is pulling it.

EXPT. 8.—Procure a flexible wooden lath, and fix it horizontally by clamping one end of it firmly. To the other end attach a pin by means of a little wax. Place a rule vertically near the pin, as in Fig. 1. A weight should then be hung from the free end of the lath, and the amount of bending observed. Keeping the same weight,

clamp the lath so that only half the previous length can be bent, and again notice the amount of bending. Try also with other lengths.

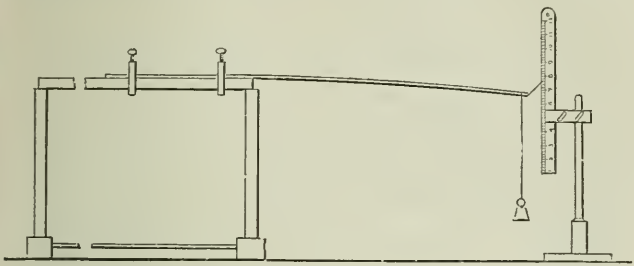

FIG. 1.—Measurement of the Bending of a Lath.

EXPT. 9.—Suspend a wire with a weight at its lower end, and under it a circle divided into degrees in a manner similar to that shown in Fig. 2. Notice the position at which the weight come to rest, then twist the weight through a certain angle, and let it go. The weight untwists back to the starting point and beyond it, and then spins in the way it was twisted, and goes on oscillating in this manner until it comes to rest. Observe how long the weight takes to make ten or fifteen complete spins. Repeat the observation with wires of different length and diameter, and made of different metals. The experiments will show you that the power to resist torsion or twisting depends, among other things, upon the length, diameter, and nature of a wire.

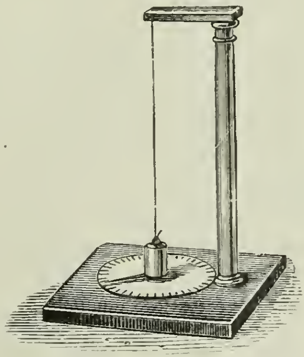

FIG. 2.—Elasticity of Torsion.

Solids possess Tenacity, Ductility, and Hardness.—Tenacity.—*Tenacity is measured by ascertaining what weight is necessary to break solids when in the form of wires.*

In making the measurement of this power, the area of the cross section of the wire must first be carefully estimated, for it is found that a wire of twice the cross sectional area of another will be just twice as tenacious. Evidently, then, if we wish to compare the tenacity of two wires of different materials it will make the experiment much simpler if wires of the same cross section are selected. Cast steel is the most tenacious of all metals, being about twice as much so as copper and forty times as tenacious as lead. But the tenacity of steel itself is exceeded by that of unspun silk, while single fibres of cotton can support millions of times their own weight without breaking.

Ductility.—The property which solids possess by virtue of which they can be made into wires, by the application of pressure suitably applied, is called *ductility*. But it must be borne in mind that it is by reason of this power that solids are made to assume other forms than wires. We can speak more generally, and say it is the power by which certain bodies change their form by the application of pressure. It includes *plasticity*, or the capability of being moulded, as well as *malleability*, by which metals like gold, copper, iron, &c., are capable of being beaten out into plates.

Platinum is the most ductile and gold the most malleable metal known. Platinum has been drawn out into wire so fine that a mile of it weighs only one and a quarter grains. Gold has been beaten into plates so thin that it would require three hundred thousand of them placed one above the other to make a layer an inch thick.

Hardness.—*Hardness* is the property by virtue of which solids offer resistance to being scratched or worn by others. This is a property of great importance to the mineralogist, as we shall learn later ; it often affords a ready means of distinguishing minerals. The method of measuring hardness consists in selecting a series of solids, each one of the series being harder than the one above it, and softer than the one below it. At one end of the series, therefore, the hardest solid known is placed ; at the other end, the softest which we may wish to measure. Since only the hardness of minerals will here be dealt with, and as the series adopted for this purpose is as good as any other, we will take the substances arranged by

Mohs, and commonly used by all mineralogists. The softest mineral is placed first.

1. Talc.	6. Felspar.
2. Rock Salt.	7. Quartz.
3. Calc-spar.	8. Topaz.
4. Fluor-spar.	9. Sapphire.
5. Apatite.	10. Diamond.

The diamond is the hardest of all bodies and scratches every other. On the above scale the hardness of an ordinary steel knife blade would be about $6\frac{1}{2}$, that is between Quartz and Felspar, or it will scratch Felspar easily but not Quartz. The healthy finger-nail has a hardness of $2\frac{1}{2}$ and, therefore, would scratch Rock Salt but not Calc-spar.

Cohesion and Adhesion.—Cohesion is the mutual attraction which the molecules of a body exert upon one another; it is the force which keeps the particles of a substance together. But for this force of attraction, solid bodies would crumble into powder. It is strongest in solids, and acts between the particles of liquids, but in gases it may be said to be absent.

EXPT. 10.—Carefully clean and polish two pieces of plate glass, and then place one on the other. The two surfaces will be found to *cohere*, and considerable force will be required to separate them.

It is by reason of the cohesion of the particles of a liquid that they are able to form drops—the larger the drop which can be formed, the greater the cohesion between the particles. Adhesion is the word usually employed to denote the attraction between unlike particles of matter. A metal plate may be made to *adhere* to glass; and a postage stamp may be said to exhibit the existence of the force of adhesion when it is stuck upon an envelope.

Characters of Liquids.—A complete treatment of the characters or properties of liquids makes up the science of Hydrostatics. But it is only necessary in this place to become aware of those leading properties which liquids possess, which distinguish them from solids on the one hand and from gases on the other. We have already learned that, being forms of matter, they have certain general characters in common with all other material things; but what is there about a liquid which

makes us give it a name of its own? *A liquid adapts itself to the shape of the vessel containing it, but the conditions remaining the same, it keeps its own size or volume, however much its shape may vary. When it is not held by the sides of a vessel it at once flows.* This is the commonest everyday experience. You cannot get a pint of beer into a glass of half a pint capacity. It does not matter what the shape of the bottle or jug may be—providing it holds a pint, as we say, or provided its capacity is a pint, the quantity of beer taken to exactly fill it is always the same. If we turn the jug upside down, the beer all runs away because there is no part of the vessel to prevent it from *flowing*. The surface of liquids, too, enclosed by a vessel is always level.

Viscosity.—This power of flowing is not perfect in liquids. The small particles making up the liquid always stick to one another a little, and when any part of a mass of liquid moves, it always attempts to drag the neighbouring particle, which is at rest, with it. We can sum this up by saying that *liquids would flow perfectly if they possessed no viscosity*. Those liquids which have little viscosity, or, what is the same thing, are very *mobile* liquids, are instanced by alcohol and water; while treacle and tar have little *mobility*, but are very *viscous*. Evidently, then, there is a gradation in those forms of matter which have as yet come before our notice. At one end we have very mobile liquids, which as the viscosity increases flow less and less easily, until at last there is no power of flowing at all, and we have the solid form of matter.

§ EXPT. 11.—Procure specimens of treacle and pitch. Soften the latter. Compare the consistency of the treacle and the softened pitch with that of water, and note the gradual increase in the viscosity of the liquids.

Distinction between Liquids and Gases.—It has been seen that the leading difference between a solid and a liquid is the power of flowing which the latter possesses. Gases also possess fluidity, and to a much more marked degree than liquids. But whereas liquids are almost incompressible, gases are very easily compressed into a much smaller space in a manner which never varies, viz., just in that proportion in which you *increase* the pressure on a gas do you *decrease* the volume which it occupies. Nor are these the only differences. A liquid always adapts itself to the shape of the containing vessel, and presents a level surface at the top; a gas, on the other hand, will, however small its volume, immediately spread out and do its best to fill a vessel, however large; and it does not

present any surface to the surrounding air. We can never say exactly where the gas leaves off and the air begins. Another distinction will be more fully appreciated after we have considered the action of heat upon the volume of bodies. We shall learn that, generally speaking, all bodies get larger as they are heated ; this is very much more decidedly the case with gases than with liquids. Gases, then, *are easily compressible and expand indefinitely.*

Liquids find their Level.—If several vessels of the most varied shapes (Fig. 3) are in communication with one another, and water be poured into any one of them, we shall find that as soon as the water has come to rest it will stand at the same level in all the tubes, however different the form of the vessels may be. It is this property of liquids which is utilised in the construction of the *water-level.* Its construction and use will be easily understood by a glance at the figure. However the doubly-bent tube may be standing, the line joining the two surfaces will always be level. This is of great service to surveyors and such people who must be able to find a level line for the purpose of their observations. The following simple experiment is useful in showing that the surface of a liquid at rest is level :—

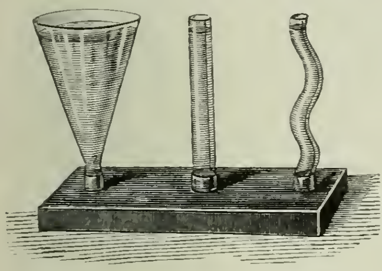

Fig. 3.—Vessels of various shapes in communication. Water standing at same level in all.

Expt. 12.—Into a shallow glass vessel pour enough mercury to cover the bottom. Attach a ball of lead to the end of a fine string, and so construct a *plumb-line.* Hang it over the surface of the mercury, and notice that the line itself and its reflection are in one and the same line. If this were not the case, that is, if the image slanted away from the plumb-line itself, we should know the surface of the liquid was not horizontal.

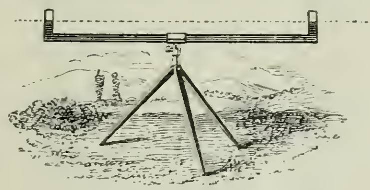

Fig. 4.—A Water-level.

Liquids communicate pressure equally in all directions.—It will be desirable first to satisfy ourselves that liquids communicate pressure, and then try to understand the second part of the statement, that they communicate it equally in all directions. Imagine we have two cylinders in connection, as shown in Fig. 5. Into each cylinder fit a piston with a plate attached to the top, as our illustration also makes clear. If we push one piston down, we notice that the other moves up. If we put a weight, say 10 lbs., on to each piston, they will exactly balance one another, and there is no movement in either case. Each piston is pressed upwards and downwards to an equal degree, and in consequence does not move at all. The experiment can be varied by making one cylinder horizontal, while the other remains vertical. In this case, also, if we push in the horizontal piston we notice that the upright piston rises in just the same manner as before, showing us that pressure is communicated *in different directions*. Finally, if we construct a vessel after the pattern of our illustration Fig. 6, with several pistons working in cylinders in connection with it, and apply a pressure to any one of them, by pushing the piston down a certain distance we shall find the other pistons are forced out to an equal extent, or pressure is communicated *equally in all directions*.

Fig. 5.—To illustrate Hydrostatic Pressure. The two cylinders are of the same size, so equal weights upon the pistons balance one another.

Hydraulic Press.—Reverting to our first example in the last paragraph, and glancing at Fig. 5, suppose that the surface of the piston on the right had been twice as great as the other, and that, as before, weights of 10 lbs. had been placed upon each piston. They will no longer balance; the right-hand weight is pushed upwards, and to bring about a balance it would be found necessary to put 20 lbs. on the larger piston. Similarly, had the right-hand piston been a hundred times larger, we should have to put 1000 lbs. upon it to bring about a balance. The upward pressure, then, is proportional to the extent of the surface of the piston. This principle, which seems so different from what we should naturally expect, is referred to as the *Hydrostatic Paradox*, and is utilised in the Hydraulic Press, called, after its inventor, the *Bramah*

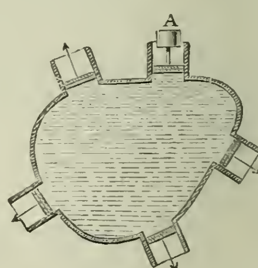

Fig. 6.—Apparatus to show water communicates pressure equally in all directions.

Press, which is shown in Fig. 7. Here we have exactly the condition of things just described, two cylinders in connection, with pistons fitted into them, one much larger than the other. The application of a comparatively small pressure to the small one is felt on the larger one, and it is as many times greater in an upward direction as the piston of B is larger in area than the piston in A. This great upward pressure is being used in the instance shown in the diagram to compress bales of wool.

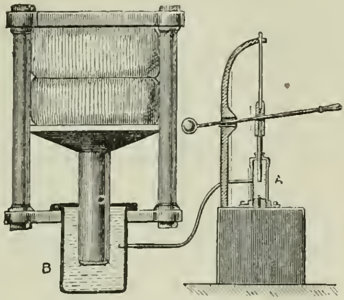

FIG. 7.—The Hydraulic Press.

We shall find this property which liquids have of finding their own level and of communicating pressure; under the conditions described, of the greatest use in understanding how springs are formed, and in explaining other phenomena which will present themselves.

Liquids can be separated into drops which will run together again.

EXPT. 13.—Sprinkle some powdered resin on a board and then a little water. Notice the water collects in *drops;* the smaller they are, the more nearly spherical they are. Observe the same thing with mercury on a sheet of paper.

EXPT. 14.—Mix methylated spirit and water until a few drops of oil just float when the mixture is quite cool. Pour fresh oil, by means of a pipette, into the middle of the mixture. Notice spherical globes of oil can thus be formed.

EXPT. 15.—Observe that drops once formed can be made to run together again by coming in contact.

Properties of Gases.—We have seen in what respects gases differ from liquids and in other connections, as, for instance, when we are studying the action of heat upon the properties of bodies, we shall learn that gases expand equally when heated to the same extent, but this fact and others will be much better understood in their proper places.

Indestructibility of Matter.—Matter cannot be destroyed. There is a certain fixed amount of matter in the universe which never gets any less and never any greater. If

we confine our attention to the earth, we cannot say that it never receives an addition to the matter of which it is built, for every year it is receiving numbers of small solid bodies which are continually falling upon its surface from outside space. But the proposition means that in those cases in which it is popularly supposed there is a loss of matter, for instance when a fire burns out, no such destruction has taken place, but only a change in the form assumed by the matter. It will make the statement quite clear if we follow out what really takes place when a candle burns, and, as it would seem, gradually disappears.

EXPT. 16.—Over a burning candle hold a white glass bottle which has been carefully dried inside and out. Observe that the inside of the bottle becomes covered with mist and after a short time drops of water are formed which run down the sides of the bottle. *The burning of the candle has resulted in the formation of a new form of matter, which we call water.*

EXPT. 17.—Allow the candle to burn in a similar bottle placed on the table. After a time the candle ceases to burn, and when this has happened take the candle out and cover the bottle over with a glass plate. Notice that no change seems to have taken place in the gas which filled the bottle. Now pour some clear lime-water into another clean bottle and shake it up, the lime-water remains clear.[1] Lift off the glass plate and do the same with the bottle in which the candle has been burnt, the lime-water turns milky. *The burning of the candle has also resulted in the formation of a new kind of matter, viz., a gas which turns clear lime-water cloudy.*

Evidently, then, when a candle burns it ceases to exist as tallow or wax, or whatever the candle is made of, and assumes new forms, still material, one water, the other a gas which turns lime-water milky. If we were to weigh all the water formed and all the gas which turns lime-water milky, we should find that these two things together actually weigh *more* than the part of the candle which has disappeared did. The reason why there is an *increase* of weight will be explained in Chap. VIII. The arrangement for performing this experiment is shown in Fig. 8. The candle is burnt in a wide tube, A, fitted with a cork at the bottom with holes in it to allow the air, which is necessary to help the candle to burn, to pass in as shown by a bent arrow. The tube B is filled with a substance which has the power of arresting the products of the burning. Such a sub-

[1] There may be a slight milkiness owing to the presence in the air of the gas which is formed. If so the experiment must be made comparative.

stance is caustic soda, which is used in the form of lumps. Air is drawn through the apparatus as shown by the arrows.

Before the experiment is started, the candle is weighed and also the tube containing the lumps of caustic soda. After the experiment the same things are weighed over again. It will be found that the tube B has increased in weight to a greater extent than that of the candle has been diminished. We are quite sure, therefore, that there has been no loss of matter.

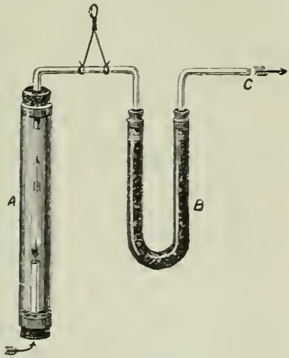

FIG. 8.—Apparatus to show that no matter is destroyed when a candle burns.

Chemists have satisfied themselves that this is universally true, and it must be remembered as a truth of the highest importance, *matter is indestructible.*

The following experiments also illustrate the indestructibility of matter :—

§ EXPT. 18.—Boil water in a flask or a retort, as in Fig. 9, and catch the condensed steam in another flask kept cool by resting in

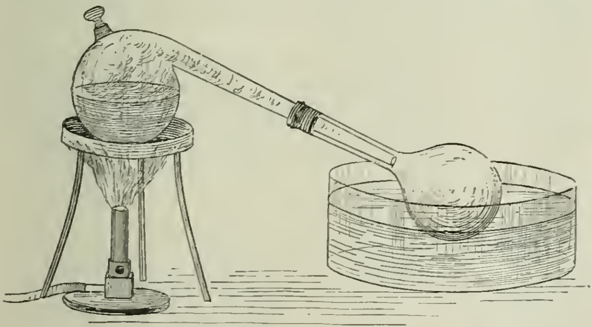
FIG. 9.—Condensation of Steam.

water, taking care that none escapes. The water thus collected will be found to have the same weight as that boiled away.

§ EXPT. 19.—Place a piece of ice in a flask suspended from one arm of a balance. Counterpoise the flask with the ice in it; then melt the ice by warming the flask, and show that the counterpoise is unaltered.

§ EXPT. 20.—Put some water in a flask and some salt in a piece of paper. Counterpoise the flask of water and the paper of salt together and then dissolve the salt in the water. The total weight remains unaltered.

CHIEF POINTS OF CHAPTER I

General Properties of Matter.—Every material thing possesses:—

Impenetrability meaning that two things cannot be in the same place at the same time.	*Inertia* that is, inability to move itself or change its state of motion.	*Divisibility* that is, is capable of being divided into distinct particles.
Porosity that is, there are pores or minute spaces between its particles.	*Compressibility* signifying that its particles can be squeezed closer together.	*Elasticity* that is, a tendency to go back to the original form or volume after being forced out of it.

In consequence of these universal properties all forms of matter take up space, offer resistance, possess weight, and can transfer motion.

Specific Properties of Matter.—Characteristics possessed by certain substances only are:—

Tenacity or the resistance offered to being torn apart.	*Ductility* or the capability of being drawn out into wires.	*Malleability* or the capability of being beaten into sheets.	*Hardness* or the resistance offered to being worn or scratched.
Viscosity in virtue of which some particles drag similar particles after them when flowing.	*Mobility* or the power of flowing.	*Cohesion* or the attraction between adjacent particles of the same kind.	*Adhesion* the force which causes unlike substances to cling together.

Forms of Matter.—Substances exist in three different forms or states, namely, solids, liquids, and gases :—

Matter.

Solids	Liquids	Gases
Have different shapes which cannot be easily altered. Have surfaces of any form.	Take the shape of the vessel containing them. Have a horizontal surface. Can be separated into drops which will run together again. Find their own level.	Fill any vessel into which they are put. Have no definite surface.

Proofs of Indestructibility of Matter.—(1) By collecting the substances produced when a candle is burnt ; (2) by boiling water and collecting the steam ; (3) By melting ice and weighing the water formed ; (4) by dissolving salt in water and showing that the weight of the solution is equal to the total weight of the salt and water separately.

Questions on Chapter I.

(1) Describe an experiment to show the porosity of a liquid.

(2) What are the distinguishing characteristics of solids, liquids, and gases ?

(3) Define tenacity, ductility, and viscosity, and name a viscous substance.

(4) State the difference between cohesion and adhesion.

(5) How would you prove that a glass marble undergoes compression when it is allowed to fall on a hard slab ?

(6) Describe two experiments to show that substances do not lose in weight when they undergo a change of state.

CHAPTER II

MEASUREMENT OF SPACE, MASS AND DENSITY

Measurement of Length.—We have from time to time in the preceding chapter referred to lengths as being of so many yards, or feet, or centimetres, and it is desirable, before going further, to acquaint the student with the exact significance of these and other measures of length. It is clear that before comparing any one length with any other we must have some standard to which we can refer them. In this country the standard adopted is the length between two marks on a platinum bar kept at the Exchequer Chambers, the bar being at a certain fixed temperature when the measurement is made. This length is quite arbitrary and is called a *yard*. The yard is subdivided into three equal parts, each of which is a *foot*. The foot is in its turn divided into twelve equal parts, called *inches*. Multiples of the yard are also used and special names given to them, thus :—

2 yards	= 1 fathom
$5\frac{1}{2}$ yards	= 1 rod, pole, or perch
40 poles	= 1 furlong
8 furlongs 1760 yards	= 1 mile

We have given these in full to show how clumsy and unsatisfactory the British measures of length are, and to point out that it is for this reason they are not used in scientific work, even by British men of science.

French geometricians decided that such an arbitrary standard was, in view of the chance of its loss or destruction, an undesirable one, and suggested that if a fraction of the circumference of the earth were taken they would, in the event of the loss

of the standard, be easily able to replace it by an exact copy. They proposed the one tenth-millionth part of the earth's quadrant, *i.e.*, the distance from the equator to the pole, as a suitable length, and this they called the *metre*. After bars had been prepared of this length it was unfortunately found that the length of the quadrant had not been exactly determined, and consequently the length of the standard metre at Paris is arbitrary, and we must define the standard metre as being the length at a certain temperature between two marks on a platinum bar kept at Paris. It is equal to 39·37079 inches. The metre is subdivided into ten equal parts, each of which is called a *decimetre*, the tenth part of the decimetre is called a *centimetre*, and the tenth part of the centimetre is known as a *millimetre*. Thus we get

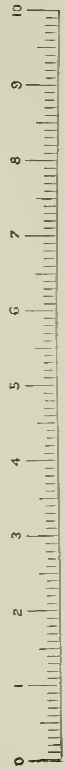

FIG. 10.—A Decimetre subdivided into centimetres and millimetres.

$$10 \text{ millimetres} = 1 \text{ centimetre}$$

$$\left.\begin{array}{r}10 \text{ centimetres}\\ 100 \text{ millimetres}\end{array}\right\} = 1 \text{ decimetre}$$

$$\left.\begin{array}{r}10 \text{ decimetres}\\ 100 \text{ centimetres}\\ 1000 \text{ millimetres}\end{array}\right\} = 1 \text{ metre}$$

The multiples of the metre are named *deca-*, *hecto-*, and *kilo-metres*. Their value is seen from the following table :—

$$\begin{array}{r} 10 \text{ metres} = 1 \text{ decametre}\\ 100 \text{ metres} = 1 \text{ hectometre}\\ 1000 \text{ metres} = 1 \text{ kilometre.}\end{array}$$

The kilometre is equal to about three-fifths of a mile.

Measurement of Area.—In speaking of the measures of area (or space of two dimensions) according to the English system we use the same names as when measures of length are referred to, simply prefixing the word *square*. Thus we speak of square inches and square feet, and since there are 12 linear inches in a linear foot, there will be $12 \times 12 = 144$ square inches in a square foot, and similarly throughout the measure. Similarly it is

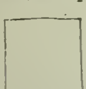

FIG. 11.—A Square Centimetre.

the custom to speak of an area, as of so many square centimetres, or square metres, as the case may be.

Measurement of Volume.—When we come to measure volumes we are dealing with three dimensional spaces ; and just as a plane surface or area measuring one foot in each of the directions, length and breadth, is called a square foot from the name of the figure which it forms, so a solid which is obtained by measuring a foot in three directions, length, breadth, and thickness, is called a cubic foot, from the name *cube* given to the solid so formed. Similarly using the French measure, or as it is more often called the *Metric or Decimal* system, we may speak of a cubic metre, or a cubic decimetre.

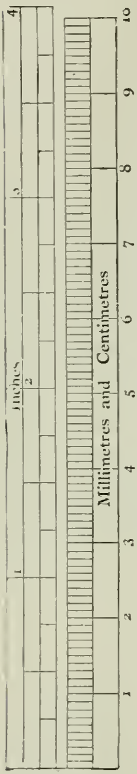

FIG. 12.—Comparison of Inches and Centimetres, &c.

The amount of space enclosed by a solid figure is called its *volume*. The volume of a solid is the space it occupies or its size. The volume of a vessel is the amount of space it encloses. In the metric system a special name is given to the volume of a cubic decimetre, that is, a cube having a decimetre edge. It is called a *litre*, and is equal to about one and three-quarters English pints. The sub-multiples and multiples of a litre are named in a similar way to those of the metre. There is no such simple relation between the measures of length and volume in the English system, though the gallon is defined as a measure which shall contain 10 lbs. of pure water at a certain temperature and pressure.

Mass.—*The mass of any body is the quantity of matter it contains.* In our country the standard or *unit* of mass is the quantity of matter contained in a lump of platinum of a certain size which is kept at the Exchequer Chambers. This amount of matter is called the imperial standard pound avoirdupois, and we speak of the mass of any other body as being a certain number of times

more or less than the standard pound, that is, containing so many more times as much (or as less) matter than that contained in the imperial standard pound. Unfortunately, this is not a universal standard; in France they have a standard of their own. It is kept at Paris and is called a *kilogram*, and the system of masses founded upon it is used in all scientific work throughout the world.

In the metric system a name is given to the mass of water which will exactly fill a *cubic centimetre* at a temperature of 4° C. It is called a *gram*. The same prefixes are used to express fractions and multiples of a gram as have been used in the case of the metre and litre. The kilogram, or unit of mass, is one thousand times greater than that of a gram, and is the unit in use for ordinary purposes.

TABLE OF MEASURES OF LENGTH, VOLUME, AND MASS.

	Length	Volume	Mass
$\frac{1}{1000}$	Milli-metre	Milli-litre	Milli-gram
$\frac{1}{100}$	Centi-metre	Centi-litre	Centi-gram
$\frac{1}{10}$	Deci-metre	Deci-litre	Deci-gram
1	Metre	Litre	Gram
10	Deca-metre	Deca-litre	Deca-gram
100	Hecto-metre	Hecto-litre	Hecto-gram
1000	Kilo-metre	Kilo-litre	Kilo-gram

VALUE OF COMMON ENGLISH EQUIVALENTS.

1 inch =	about $2\frac{1}{2}$ centimetres.	1 gallon	= about $4\frac{1}{2}$ litres.
1 foot =	„ 3 decimetres	1 oz. Troy	= „ $31\frac{1}{10}$ grams
1 yard =	„ $\frac{9}{10}$ metre	1 „ Avoir.	= „ $28\frac{2}{5}$ „
1 mile =	„ $1\frac{3}{5}$ kilometre.	1 lb. „	= „ $\frac{9}{20}$ kilogram.

Density.—Equal volumes of different substances have different masses. This truth is expressed by saying they have different densities.

§ EXPT. 21.—Procure equal volumes of different substances, *e.g.*, a cubic inch of wood, lead, cork, marble, and determine their masses by means of a balance. Notice they are different.

EXPT. 22.—Compare the volume of a pint of water with that of one

and a quarter pounds of iron. Observe their masses, as determined by a balance, are equal, but their volumes very unequal.

§ EXPT. 23.—Fill two equal flasks with water and methylated spirit respectively, and weigh. Show the weights are different.

If we keep to the unit of volume, the numbers representing the masses of this volume of the kinds of matter we experiment upon are a direct measure of the densities of these bodies. We can thus define it :—*Density is the mass of a unit volume of a substance.* It follows from this definition that if the volume of a body is multiplied by its density, we shall obtain its mass

$$\text{volume} \times \text{density} = \text{mass}$$
$$\text{or density} = \frac{\text{mass}}{\text{volume.}}$$

In using this relation between the volume and mass care must be taken to use the proper units. In all scientific work it is customary to adopt the cubic centimetre and gram as the units of volume and mass respectively.

Density can be regarded in another way. It is clear that if we pack twice the amount of mass into a given volume we shall have doubled its density, so that density may be looked upon as the closeness with which mass is packed into a given volume.

When we use the cubic centimetre and gram as the units of volume and mass and apply the equation given above, the density of water works out to be one ; for all other forms of matter the number will be either a fraction or multiple of this value. Whenever a standard is employed in this way and other things are compared with it, we obtain a proportion or ratio, or a *specific* value. It is in this way that the expression *specific gravity* has grown up to designate the density of a body. We shall see that weight is due to the mutual attraction between masses of matter, and that the weight of bodies forms a convenient mode of comparing their masses. The word "gravity" was first used with exactly the same meaning as we use "weight," and hence we see that "specific gravity" or "specific weight" means nothing more than *the proportion between the weight of a given volume of a substance and the weight of an equal volume of water.* This way of defining density enables us to remember easily the methods by which it is experimentally determined.

Methods of measuring Density.—*Method with Chemical Balance.*—There are two numbers which we wish to determine :—(i) The weight of the body of which the density is required, *i.e.*, its weight in air ; (ii) the weight of an equal volume of water.

The first number can be obtained directly by putting the body upon one scale-pan and accurate weights on the other, until the weight of the body is exactly balanced. This only requires practice to be able to accomplish it with the greatest precision.

To ascertain the second number, we utilise a property of water to which we have not hitherto called the student's attention. When a body is placed in a vessel of water, as every one knows, the level of the water is raised, or, as we say, the body *displaces* some of the water. Experiment shows that the body displaces exactly its own volume of water, and, further, that if we weigh the body while it is thus displacing water we shall find that it weighs less than when weighed in the air. *The loss of weight is the weight of an equal volume of water*, or the weight of water displaced by the body. Hence, to find the second number, all we have to do is to suspend the body by means of a thread from a hook on the undersurface of the scale-pan, and allow it to hang freely suspended in pure water, as in Fig. 13, and to counterpoise it with weights. This will give us the weight of the body in water. The difference between the body's weight in air and its weight in water is the weight of an equal volume of water, which is the second number required. The proportion between these two numbers, *i.e.*, the first divided by the second, is the density of the body.

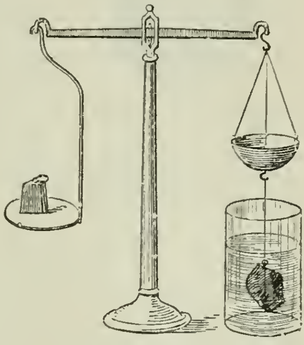

FIG. 13.—Determination of Specific Gravity with a Balance.

$$\frac{\text{Weight of body in air}}{\text{Weight of body in air} - \text{Weight of body in water}} = \frac{\text{Weight of body}}{\text{Weight of an equal volume of water}} = \text{Density.}$$

The above experiment should be varied by using a spring balance for weighing.

Specific Gravity Bottle.—Consists of a small glass flask, holding about 50 grams of water. It is provided with a nicely-fitting ground stopper, which is in the form of a tube with a very small bore through it. It is used in determining the specific gravity of liquids and powders. To use it, we must first know the weight of the empty bottle and stopper. The bottle is then filled with pure water, the stopper

inserted, and the water which is forced through the hole in the stopper wiped off, and the bottle and its contents weighed. In this way the weight of water which just fills the bottle is found. If now we empty the bottle and carefully dry it inside and out, and fill it with the liquid of which the density is required, say spirits of wine, and weigh again, we have the weight of the liquid which just fills the bottle, or the weights of equal volumes of the liquid and water, the proportion of which gives us the density of the liquid.

FIG. 14.—A Specific Gravity Bottle.

§ EXPT. 24.—Counterpoise an empty specific gravity bottle, or a flask having a mark on its neck. Fill the flask up to the mark with methylated spirit and weigh it; then empty the flask, dry it, and fill with water up to the same mark. Weigh again, and from the two weights find the specific gravity of the spirit.

The principle applied in the case of powders is identical, though there are certain differences in the weighings which must be taken.

TABLE OF DENSITIES.

Solids and Liquids at 0°C. compared with water at 4°C.[1]

Solids.	
Platinum (rolled)	22·069
Gold (stamped)	19·362
Lead (cast)	11·352
Silver (do.)	10·474
Copper (do.)	8·788
Steel (not hammered)	7·816
Iron (cast)	7·207
Heavy spar (barium sulphate)	4·430
Diamond	3·531 (varies)
Marble	2·837
Rock crystal	2·653
Anthracite	1·800
Coal (compact)	1·329
Melting ice.	0·930
Oak	0·845
Cork	0·240

Liquids.	
Mercury	13·598
Bromine	2·960
Sea water	1·026
Distilled water (4°C.)	1·000
Olive oil	0·915
Alcohol (absolute)	0·793

Density of Gases.—The density of a gas is not compared with that of water as a standard, because the number which would be obtained by such a comparison would be so exceedingly

[1] The reason for specifying the temperatures will be quite clear after the Chapter on "Heat" has been read.

small. The standard density adopted is that of the gas hydrogen, which is the lightest form of matter known. The densities of other gases will in every case therefore be greater than unity. To find the density of a gas, all that it is necessary to do is to weigh a flask filled with pure dry hydrogen under certain conditions of temperature and pressure (*see* Chap. XIII.), and then to weigh the same flask filled with the gas of which the density is required under the same conditions of temperature and pressure; the number of times the gas is heavier than hydrogen is the number representing its density. There are several important precautions which have to be adopted, but for an account of these we must refer the student to works on chemistry.

Densities of Gases.

Hydrogen	1·0
Nitrogen	13·9
Oxygen	15·9
Chlorine	35·2
Ammonia	8·45
Steam	8·95
Carbon monoxide	13·90
Carbon dioxide	21·85

Chief Points of Chapter II.

Units of Length.

Metric	British
Metre (= $1\frac{1}{11}$ yard)	Imperial yard
10 Decimetres 100 Centimetres 1000 Millimetres	3 feet 36 inches

Mass means quantity of matter. The British Standard unit of mass is the Imperial Pound avoirdupois, and the metric standard is the Kilogram.

Volume means the amount of space occupied or enclosed by a solid figure. A cube of which each edge is one foot long has a volume of one cubic foot.

Density means the quantity of matter, that is, the mass of a unit volume of a substance.

Specific Gravity is relative density or relative weight, and is determined by finding the weight of a substance compared with the weight of an equal volume of water at the same temperature.

Methods of Determining Specific Gravity of Solids.—(1) Find weight of the object chosen; (2) find the weight of the volume of water displaced by the object. Then

$$\text{specific gravity} = \frac{\text{weight of object}}{\text{weight of water displaced.}}$$

Methods of Determining Specific Gravity of Liquids.—(1) Weigh the water which completely fills a flask, or fills it up to a fixed mark; (2) weigh the liquid which fills the bottle up to the same mark. Then

$$\text{specific gravity of liquid} = \frac{\text{weight of known volume of liquid}}{\text{weight of equal volume of water.}}$$

Method of Determining Specific Gravity of Gases.—(1) Find the weight of pure dry hydrogen which fills a flask under known conditions of temperature and pressure; (2) find the weight of an equal volume of gas under the same conditions. Then

$$\text{specific gravity of gas} = \frac{\text{observed weight of gas}}{\text{observed weight of hydrogen.}}$$

Questions on Chapter II.

(1) Write down the length of a metre in yards, feet, and inches. How many centimetres are there in a metre, and how many millimetres in a centimetre?

(2) State how many millimetres and centimetres are equal to the length of an inch

(3) Define mass and name the units of mass in the British and French systems of weights.

(4) Describe an experiment to prove that equal volumes of different substances have different masses.

(5) How would you find the specific gravity of a marble?

(6) How would you find the specific gravity of some milk?

(7) Describe an experiment to prove that a substance is lighter in water than in air.

CHAPTER III

MOTION, INERTIA AND FORCE

Definition of Motion.—The word *motion* is meant to convey the idea of *change of place*. The simplest forms of motion are changes in the positions of bodies with regard to one another. When a boy runs down the street he is in *motion*; as regards the houses and lamp-posts he moves. To fully describe the boy's motion it would be necessary to know the *direction* in which he is moving or the *line* along which he runs, and the *rate* or *velocity* with which he travels. If during every second through which he moves he travels over a line of five yards in length, we should say he had a *uniform* velocity of five yards a second.

But suppose this boy does not move regularly over five yards in every second; he sometimes dawdles, sometimes stops to look at a shop, at other times he puts on a spurt to make up for lost time. How should we describe his motion now? His rate varies from time to time, or his velocity is *variable*, and to describe such a variable velocity it is usual to speak of the velocity *at any instant* as being a certain number of yards per second. Say the boy of our example, moving with a variable velocity, has at a given instant a velocity of eight yards per second. We should mean that he would if he continued to move at the same rate as he had at the given instant travel over eight yards in the succeeding second.

But it is sometimes better to find the *average velocity* of the moving body. Returning to our boy, suppose he travelled 800 yards in 400 seconds; if we divide the first number by the second we obtain the boy's average rate, namely, two yards in a

second ; this, then, is the rate with which he would have had to travel, if he moved uniformly, in order to complete his journey in the same time.

The unit of velocity is generally taken as being a velocity of one foot per second. Thus a velocity of six means a velocity of six feet per second.

Acceleration.—An express train starting from a terminus begins to move slowly, and, as the journey proceeds, the rate of motion goes on increasing until it gets its full speed. A stone let fall from a height similarly starts from rest, and as it moves it goes faster and faster until brought to a standstill again on reaching the ground. Or we might imagine a cyclist starting for a run, and regularly increasing his speed until he could not go any faster. In all these examples the velocity of the moving body has regularly changed and the rate at which the change has taken place is spoken of as *acceleration.*

Acceleration is the Rate of Change of Velocity.—But it may be of an exactly opposite kind to the instances given above. Reverse each of the examples and consider what happens. An express train going at full speed approaches a station and its velocity is regularly diminished until it is brought to rest at the platform. A stone is thrown upwards with a certain velocity, it moves more slowly and more slowly until it comes to rest, and then starts falling. A cyclist travelling at full speed slackens his rate regularly until he comes to a standstill. In all these cases we have examples of an acceleration of an exactly opposite kind to the previous instances, but yet an acceleration. In ordinary language this kind of acceleration is given a name of its own, *retardation.*

In measuring a regular or *uniform acceleration*, we must know what addition or subtraction to the velocity of the moving body there has been during every second of its journey. Suppose there is an addition of one foot per second to the velocity of a moving body, and that it has taken one second to bring about this change, we should refer to this as an acceleration of one foot per second in a second, or *one foot per second per second.* An acceleration which increases the velocity is referred to as *positive*, while that which diminishes it is *negative.* The first examples given above are instances of positive acceleration, while when we reverse them they afford cases of negative acceleration.

Velocities and Accelerations can be completely represented by Straight Lines.—To completely under-

stand a velocity all we want to know are its magnitude, or the distance travelled in a given time, and its direction. In the same way, we know all about an acceleration if we are aware of its magnitude and the direction of the velocity to which it gives rise. But, as is well known, a straight line can be drawn in any direction and of any length ; and we can arrange that its length shall contain as many inches or feet, whichever is more convenient, as there are feet or yards per second of velocity, depending on the way in which we decide to measure our velocities. We can therefore completely represent velocities by straight lines.

Composition of Velocities.—Imagine a marble moving along a tube with a uniform velocity, and that the tube itself is all the time being uniformly moved across a table. It is evident that since the marble is in the tube it must have the same velocity *across* the table that the tube has ; and at the same time it moves along the tube, that is, in a direction at right angles to its former velocity. It has two independent velocities. Similarly, we can think of a ship sailing across the ocean with a man on deck walking from one side of the ship to the other. The man has two velocities. He is moving onwards with the ship at a certain velocity and at the same time he is moving across the ship with another velocity.

But yet a body can only move at any instant in one direction with one definite velocity. How, then, shall we find the actual velocity at any instant in the case of the marble or of the man? The velocity which we want to find is called the *resultant* of the two independent velocities, which are themselves spoken of as *components*. If the two velocities have the same direction, all we have to do is to add them to obtain the resultant, or if they are in opposite directions along the same straight line we subtract them. If they have directions which make an angle with one another, it is clear that the resultant must be somewhere between. Referring to the case of the marble, let OA (Fig. 15) represent by its length the number of feet the marble moves along the tube in a second, and OB the distance moved by

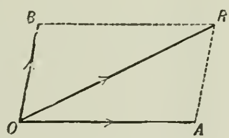

Fig. 15.—Parallelogram of Velocities.

the tube, and consequently by the marble in the same time across the table. The arrows give the direction of the movement. Draw BR parallel to OA and AR parallel to OB, thus completing the parallelogram, then the line OR represents the resultant velocity, both in magnitude and direction. In just the same way OA could stand for the ship's velocity and OB for the man's, then OR would represent the direction and magnitude of the man's actual velocity. This principle is called the *Parallelogram of Velocities*. The same method can be used to compound accelerations.

Newton's First Law of Motion.—*Every body will continue in its state of rest or of uniform motion in a straight line, except in so far as it is compelled by impressed force to change that state.*

This statement is called a *law* of motion, and as it is the first time this word has been used, it will be well to make clear at once that a natural law is only an expression of what has been found to always be the rule; it is merely setting down the result of experience; and the idea of the word in its legal sense must be carefully excluded from the mind. Indeed, in nearly every case, it is better to substitute, at all events in one's mind, the word *rule*. It is only a statement that certain things always seem to take place; it tells us nothing about why they do so; nor is the idea of compulsion included at all, for oftentimes so-called "laws" have been formulated which have turned out to be wrong expressions of the order of nature, and evidently there could be no sort of compulsion about what was wrong, and was seen afterwards to be contrary to the general rule.

This rule, which Newton first stated as being always followed by bodies in nature, means, first, that if a body is at rest, it will remain still until there is some reason for its moving—until some outside influence, which he called a *force*, acts upon it. This law supplies us, as we shall more clearly see in a succeeding paragraph, with a definition of force. Nobody finds any difficulty in understanding the rule so far.

But when we come to consider the second part of the law there is more difficulty in grasping it—every body will continue in a state of uniform motion in a straight line, &c. An example is afforded by a ball in moving uniformly along ice. We know that after a time the ball comes to rest and therefore that it does not continue in a state of uniform motion. But we know that it moves for a longer time on ice than it would do on a

road. The ice is smoother than the road, and there seems to be a connection between the roughness or smoothness and the length of time during which the ball moves. If we imagine smoother and smoother ice, the ball will move for a longer and longer time, and we conclude that if both the ball and the ice were perfectly smooth, there is no reason why the ball should ever stop. The roughness or friction is then, in our example, the "impressed force" which causes the ball to change its state of uniform motion for one of rest. If we could have a body in a state of uniform motion outside the influence of what Newton has called "impressed forces" it would afford us an example of *perpetual motion.* But because we cannot eliminate these impressed forces we cannot have perpetual motion.

Inertia.—In enumerating the general properties of matter in Chapter I., we mentioned that one of them was the possession of inertia. We are now able to understand what this means more fully. *Inertia is the inability shown by a material body of itself to change its condition of rest or of uniform motion.* We become aware of the inertia of matter most unpleasantly if we step out of a moving train on to the platform; while in the train we partook of its motion, on stepping out our feet are brought to rest suddenly, but our bodies, because of their inertia, continue to move with the velocity of the train, with the result that we fall forwards on to our faces. The difficulty of moving a heavy body is also a familiar example of the same property.

Definition of Force.—As we have stated, Newton's first law enables force to be defined. *Force is that which produces, or tends to produce, motion in matter; or alters, or tends to alter, the existing motion of matter.* Here again it must be clearly understood that by defining force we do not get to know anything more about it. Nobody can tell what force is. All we can know are the effects produced by a *something* we call force.

Momentum.—*The momentum of a body is the quantity of motion it has, and is equal to the product of its mass and its velocity.* The unit of momentum will consequently be that of a unit of mass moving with a unit of velocity, or if the unit of mass be that of the imperial standard pound, the unit of momentum will be the quantity of motion in a mass of one

pound moving with a velocity of one foot per second. The meaning of momentum will be better grasped after an example. Suppose a shot fired from a cannon, the *momentum* generated in both the cannon and the shot will be the same; but since the mass of the cannon is immensely greater than that of the shot, it will be evident that the velocity of the shot must be correspondingly greater than that of the cannon in order that the product of the two quantities may be the same. This we know is the case, the velocity of the "kick" or "recoil" of the cannon is very much less than the velocity with which the shot is sent on its journey.

Unit of Force.—We are now in a position to understand a definition of the unit of force. It has been explained that force is the name given to the something which is able to set a body at rest in motion or to change the motion of a moving body. *A unit force acting for the unit of time is able to produce a unit of velocity in a unit of mass; or a unit of force produces a unit of acceleration in a unit of mass.* But since the product of a mass and its velocity is spoken of as the momentum of the body, we can measure force by the momentum it generates, the unit force giving rise to the unit of momentum.

Newton's Second Law of Motion.—*Change of motion is proportional to the impressed force, and takes place in the direction in which that force acts.* This law speaks of "change of motion," and by motion is understood momentum or quantity of motion. It states that the momentum generated by a force of two units will be twice as great as that produced by one unit; and further it implies that a force of one unit acting for two seconds will produce twice the momentum which it would do if it only acted for one second. This is why it is necessary in defining the unit of force to introduce the words "acting for the unit of time." The change of motion spoken of in the law must therefore be understood to mean that produced in a unit of time, or the *rate* of change of motion or momentum. But we know that the momentum of a body is the product of the mass of the body into the velocity, and since the mass remains constant, the rate of change of momentum must be the product of the mass and the rate of change of velocity, which, is as we have seen, the acceleration. Hence we come to the very important fact that *the number of units of force in any force is*

equal to the product of the number of units of mass in any body on which it may act, and the number of units of acceleration produced in that mass by the force in question.

Gravitation.—It is a matter of everyday observation that bodies free to move gravitate, as we say, towards the earth ; or as it is sometimes expressed, the earth attracts all the bodies to itself. Experiments and observations made by Newton led him to the conclusion that it was the rule of nature for every body to attract every other body, and that this force of attraction is proportional to the body's mass, a large mass exerting a greater force of attraction than a small mass. But the farther these bodies are apart the less will be the attraction between them though it is not less in the proportion of this distance but in that of the square of the distance. This diminution of a force according to the inverse proportion of the square of the distance applies to so many cases that it ought to be clearly understood before going further. To give an example : two bodies of equal mass are one foot away from one another and attract each other with a certain force, call it a unit force. One body is now moved until its distance is two feet away from the second body, what will be the force of attraction between them? The square of 2 is $2 \times 2 = 4$ and the inverse of 4 is $\frac{1}{4}$, therefore the force of attraction is one quarter of the unit force. In the same way, if the bodies were three feet apart, the force of attraction would be $\frac{1}{9}$ of the unit force. Putting Newton's law together it stands thus. *Every body in nature attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them ; and the direction of the force is in the line joining the centres of the bodies.*

Returning to the case of the falling body, think of a cricket ball on the top of a house. The earth attracts the ball, and, by Newton's law, the ball attracts the earth. The ball, if free to move, falls to the earth ; to be correct, however, we must think of the ball and the earth moving to meet one another along the line joining their centres. But the ball moves as much farther than the earth as the earth's mass is greater than the ball's ; and for practical purposes this is the same as saying that only the ball moves and that the earth remains still. Were our methods of measurement sufficiently refined we should of course be able to measure the small amount of the earth's movement.

This force of attraction between all material bodies is called the force of gravity, and we will point out that this again is only a name. Calling

this force "gravity," and the rule according to which it acts the "law of gravity," does not teach us anything about the nature of the force itself.

Weight.—*The weight of a body* is the force with which *it tends to move towards the earth.* We see at once the difference there is between mass and weight. One is matter the other is a force. When we speak of a mass of one pound we have seen that it means nothing more than the amount of matter in a certain lump of iron or other material; but when we speak of the weight of one pound we mean the force with which the mass of a pound tends to move towards the earth. The student will do well to clearly understand this distinction before proceeding.

EXPT. 25.—Hang a piece of iron from a spring balance and notice the weight indicated. The iron has a certain mass, or consists of a certain quantity of matter. Bring a strong magnet under the iron, and again notice the indication of the pointer of the balance. Evidently the quantity of matter or mass of the iron has not changed during the experiment, but the attraction of the magnet causes the apparent weight to increase.

Bearing this definition of weight in mind, it will be clear from Newton's law of gravitation that since a mass is farther away from the earth (which acts exactly as if its whole mass were collected at its centre) when it is on the top of a mountain than when at the sea-level, the weight of this mass ought to be more at the sea-level for it is nearer the centre than at the mountain top when it is farther away. This is found to be the case, but to actually demonstrate the difference in weight we must measure the weight by a spring balance. The reason for this will be seen later.

Similarly, because the earth is not a perfect sphere but is flattened at the poles, points at the surface of the earth in the region of the tropics are at a greater distance from the centre than points in the neighbourhood of the poles. Consequently the weight of a mass situated on the earth in the tropics is less than the weight it would have if it is moved into the polar regions. This has been found to be the case ; a body weighing 191 ounces when near the equator will weigh 192 ounces if moved near to the poles.

Parallelogram of Forces.—Forces can be compounded in a similar way to velocities. The construction given on p. 29

is applicable here; if the lines OA, OB represented in magnitude and direction two forces acting upon O, then OR will be the *resultant* of the two forces, both its magnitude and its direction.

This proposition is usually stated thus:—*If two forces acting at a point be represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces will be represented in magnitude and direction by that diagonal of the parallelogram which passes through this point.*

EXPT. 26.—Round two pulleys or very smooth pegs A and B (Fig. 16), pass a fine thread to which two unequal weights are attached. To

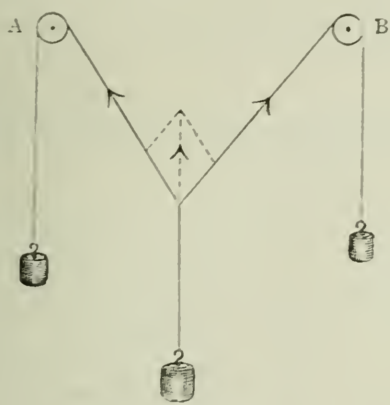

FIG. 16.—Experiment to prove the Parallelogram of Forces.

some convenient place on the thread tie a third weight as shown. Let the masses come to rest. It will be found that a parallelogram may be constructed, the sides and diagonal of which are nearly proportional to the weights used. They would be just proportional if the pegs were quite smooth.

The following is another means of illustrating the parallelogram of forces:—

§ EXPT. 27.—Attach a scale of inches to the edge of a blackboard. Obtain two pieces of thin india-rubber cord twenty inches long, and

fasten small loops of string to the two ends. Pin one of these loops to the board so that the upper end of the india-rubber cord coincides with the zero of the scale. Attach the upper end of the other india-rubber cord to any convenient point on the board. Bring the two lower ends together and hook on to them a weight (say of 100 grams). Measure off twenty inches from the upper end of each cord. The excess of length in each cord will be proportional to the tension of that cord. Complete the parallelogram with chalk, and show that the diagonal is vertical and is equal to the extension of the cord when it hangs vertically by the side of the scale with the weight attached.

Conversion of Rectilinear into Circular Motion.—It has already been explained (p. 30) that any object, once set in motion, moves in a straight line unless the action of external power prevents it from doing so. If, therefore, a body is moving in a curve, this is because it is being continually pulled out of its rectilinear path by some force.

EXPT. 28.—Tie a ball to one end of a piece of string; hold the other end of the string in your hand, and swing the ball so that it moves around your hand in a circle. In this case, the tension of the string converts the would-be rectilinear motion of the ball into circular motion.

Let A*d* (Fig. 17) represent the string used in Expt. 28, the ball being at A. You will understand from what has been said about the resultants of forces that, if there is a force constantly pulling in the direction of the central point *d*, as well as the tendency to move in a straight line, the ball will not arrive at O after the lapse of, say, a second, but at *c*, having travelled along the curved path A*c*. The short line O*c* thus represents the pull of the string, or of the central force, at *d*. The same kind of action may be considered always to go on when an object moves in a curve; in other words, any small piece of the curve represents the resultant of two forces—one acting in the direction of a fixed point, and the other being the moving force or inertia which tends to make the object keep in a straight line. It can be shown that, in all cases

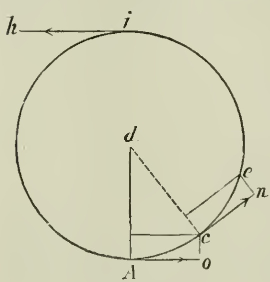

FIG. 17.—To explain Motion in a Circle.

when an object moves around a central point in the manner described, the pull towards the centre, whether it is represented by the tension of a string or by an attraction of some kind—is equal to the mass of the moving body multiplied by the square of the velocity, and divided by the distance from the centre to the object.

An example of motion in a curve around a centre of force, and also of the parallelogram of forces, is afforded by the moon, which moves around the earth in nearly a circular path on account of their attraction for one another. If this attraction of gravitation did not exist, the moon would leave us altogether, just as surely as the ball whose motion is represented in Fig. 17 would fly off in the direction *ih* if the string which forced it to move in a circular path were cut when the point *i* was reached.

The following experiment illustrates the rectilinear tendency referred to in the foregoing :—

§ Expt. 29.—Attach equal short threads to the outer edge of a circular card with a hole in the centre. Fasten light pith balls to the free ends of the threads. Slip the card over the upper part of a top while spinning, and observe the behaviour of the balls.

Other experiments upon this subject are described in connection with the rotation of the earth.

Resolution of Forces.—A single force can be replaced by other forces which will together produce the same effect. Such a substitution is called *resolving* the force or a *resolution* of the force. The parts into which it is resolved are spoken of as *components*. When this has been done it is clear that we have made the original force become the resultant of certain other forces which have replaced it. Referring back to what has been said about the parallelogram of forces, it will be seen that any single force can have any two components in any directions we like ; for by trying the student will be able to make any straight line become the diagonal of any number of different parallelograms. The most convenient components into which a force can be resolved are those the directions of which are at right angles to each other. In this method of resolution, neither component has any part in the other. A very important application of this resolution of a force into two components at right angles is found in the consideration of the force which causes the needle of a mariner's compass to oscillate. In this case it is that part

of the total force of the earth's magnetism which acts in a horizontal direction which causes the oscillation, the vertical component having no part in the action, being completely taken up in vainly endeavouring to make the needle move in an up and down direction.

Newton's Third Law of Motion.—*Action and reaction are equal and opposite; or the mutual actions of two bodies on one another are always equal and in opposite directions.*

This law can be exemplified in a variety of ways. If you press upon the table with your hand with a certain force, the law asserts that your hand is pressed by the table with an equal force in the opposite direction. We say in common language simply that the table offers resistance. Similarly, if you hold a mass of a pound on the palm of your outstretched hand it presses your hand downwards with a force which we have learnt is called its weight ; your hand presses the weight upwards with a force of exactly the same amount. If the scrimmage at Rugby football does not move, it is clear that the opposing "forwards" are pressing one another with equal forces in opposite directions, and it is easy to understand in this case that the action and reaction are equal and opposite. Every force, then, is *one* of a pair of forces, the second being the reaction to which it gives rise. Such a pair of forces is called a *stress.*

Examples of Stresses.—*Tension is an instance of Stress.* When a horse is drawing a heavy load by means of a rope the horse is drawn in the opposite direction by a force equal to that exerted by the horse through the rope. To the forces acting through the rope the name *tension* has been given—the tension is clearly paired, and affords an instance of stress.

Attraction is a Stress.—In the example of a mass held on the hand, we have a case of attraction, the earth attracts the body and the body attracts the earth, and this gravitational action and reaction, commonly called the force of gravity, is an instance of stress with the special name of *attraction.* Evidently both tension and attraction are examples of stresses which tend to bring matter closer together.

Repulsion is a Stress.—When the marked end of a magnet is brought towards the marked end of a compass needle we notice that the needle is *repelled*, or driven away, if it is free to move. But the needle repels the magnet with the same force that the

magnet repels the needle ; in fact, if the magnet is hung in a sling so that it can turn easily, its marked end will be found to be repelled by the marked end of the compass needle. Here we have, then, an example of *repulsion*, and since it is mutual, it affords an illustration of the third law of motion and is another instance of stress.

Chief Points of Chapter III.

Change of place = motion : rate of change = velocity : rate of change of velocity = acceleration.

Velocity.

- Uniform — Equal distances travelled over in equal times.
- Variable
  - Regular = Acceleration, or rate of charge of velocity.
  - Irregular

First Law of Motion.—Every body remains at rest, or continues in motion in a straight line, unless it is compelled to change that state by a force acting upon it.

Second Law of Motion—Change of motion is proportional to the acting force, and takes place in the direction in which the force acts.

Third Law of Motion.—Action and reaction are equal and opposite ; or the mutual actions of two bodies on one another are always equal and in opposite directions.

Force is that which changes, or tends to change, a body's state of rest or motion.

The Unit of Force is the force which produces unit acceleration upon unit mass.

Momentum is quantity of motion, and is measured by the product of mass and velocity.

The Law of Gravitation.—Every particle in nature attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$\text{Gravitational attraction} = \frac{\text{Mass} \times \text{mass}}{\text{Square of distance between them.}}$$

Weight is the force with which a body tends to move towards the earth.

Parallelogram of Forces.—When two forces acting upon a point are represented in magnitude and direction by the adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal which passes through that point.

Stress is the mutual action between two portions of matter; attraction, repulsion, tension, pressure, torsion, &c., are phenomena produced by various stresses.

§ **Angular Velocity.**—If a body moves in a circle a force must act towards the centre of the circle. If the force suddenly ceases to act the body moves on in a straight line and thus departs from the centre of the circle. Hence curvilinear motion is an effect due to the inertia of the moving body and a force which pulls the body towards the centre of motion.

Questions on Chapter III.

(1) Illustrate by a drawing and an example the parallelogram of forces (1896).

(2) Define force, momentum, stress (1895).

(3) Give a definition of *velocity*, and state how uniform linear velocity is measured.

(4) Describe the meaning of *inertia*, and illustrate your description by two examples.

(5) What are the laws of motion?

(6) State the law of gravitation, and show briefly how its action and the moon's inertia cause the moon to move in a nearly circular path around the earth.

CHAPTER IV

PARALLEL FORCES AND MECHANICAL POWERS

Parallel Forces.—So far only the effects of forces acting in different directions have been considered ; it is now necessary to describe a few simple cases of the actions of parallel forces. To begin with, it will be evident that if two equal parallel forces act in the same direction upon a body, the total force will be obtained by adding the two individual forces together. And, in like manner, if two unequal parallel forces act in opposite directions the net effect will be found by subtracting the lesser of the two forces from the greater, and the direction of the resultant will be that of the greater force. This simple principle is expressed as follows :—"The resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction." A few experiments will show that this rule is true.

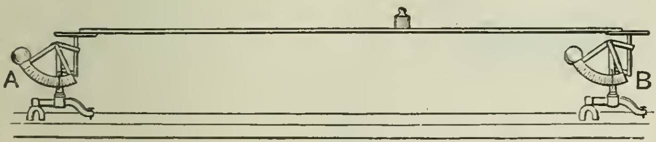

FIG. 18.—Parallel Forces in Equilibrium.

EXPT. 30.—Place the ends of a light stiff lath upon two letter balances A, B, as in Fig. 18, and notice the reading indicated by each balance. Put a weight upon the lath, and write down the increase of value shown by each balance.

The total of the two numbers thus obtained will be found to be equal to the weight employed; in other words, the sum of the two upward forces exerted by the balances is equal to the downward force due to the weight. The following experiments also illustrate this principle :—

§ EXPT. 31.—Suspend a light stiff rod by a string which passes over a pulley and has attached to its other end a weight equal to that of the rod. The rod can then move as if it were weightless. Fasten a spring balance to a convenient point on the rod. Suspend weights at the extremities of the rod so that they balance about this point, and show that the magnitude of the resultant is equal to the sum of the weights.

§ EXPT. 32.—Attach an additional weight to the string, which is fastened to the centre of the rod, and also weights to the ends, so that the rod is in equilibrium. Show that the pull on the balance is equal to the difference of the forces which act downwards and upwards respectively.

Centre of Gravity.—When a stone, or any other body, is suspended by a string, every particle of it is being pulled downwards by the force of gravity. A set of parallel forces, all acting vertically downward, is thus acting upon the stone, and their resultant may be represented by the line GF in Fig. 19. For the stone to be in equilibrium the string must be parallel to GF; it acts in the opposite direction. The point G, which represents the point of application of the resultant of the forces of gravity, is known as the *centre of gravity* of the body.

FIG. 19.—Parallel Forces due to Gravity.

Methods of Determining Centre of Gravity.

EXPT. 33.—Obtain several sheets of zinc or cardboard cut into various shapes as shown in Fig. 20, and drill holes in the positions indicated. Using one at a time, tie pieces of string to the sheet, passing each through one of the holes. Hang the piece of zinc by one of the strings to a support such as one of the rings of a retort stand. Allow it to come to rest and draw a chalk mark across the piece of zinc in the same straight line with the string as shown by the dotted line in the figure. Now attach the same piece of zinc by one of the other threads exactly as before and again make a mark in continuation of the string.

The two chalk marks intersect at a point G, Fig. 21. Untie and do the same with another string, the third line passes through the inter-

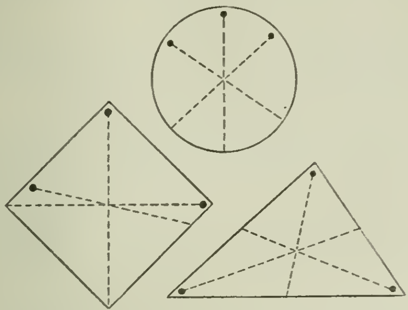

FIG. 20.—Figures for the Determination of Centres of Gravity

section of the first two. Obtain a similar point for each of the other pieces of zinc.

EXPT. 34.—Balance the pieces of zinc, one after the other, upon a

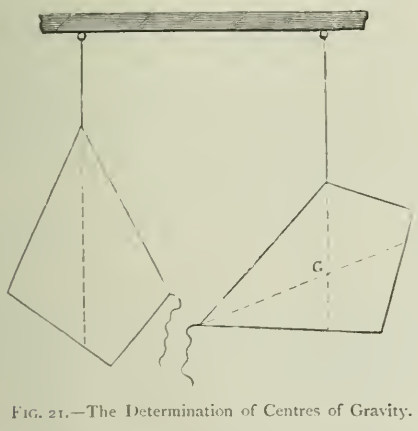

FIG. 21.—The Determination of Centres of Gravity.

pointed upright, at the intersection of the chalk marks; each will be found to set itself in a horizontal position.

The point so obtained is the *centre of gravity*, and is the point at which the mass of the pieces of zinc seems to act. The plates are attracted by the earth precisely as if all the mass of the sheets were collected at these points. The centre of gravity of certain regular figures should be remembered, thus the centre of gravity of all circular plates is at their centre, and of all square plates at the intersection of two diagonals.

§ EXPT. 35.—Procure a skeleton cube and suspend it as in the preceding experiment. Mark the verticals through the point of suspension by light wires attached by wax, and thus find the position of the centre of gravity.

Principle of the Lever.—A lever is a rigid bar which can be freely turned about a fixed point known as the *fulcrum*. To understand the action of any lever, it is only necessary to have a clear knowledge of the forces at work. For convenience, levers are sometimes divided into three orders or classes according to the positions of the fulcrum, force employed, and resistance to be overcome. The simplest case is when the fulcrum is between the two forces, as in a see-saw, a balance, and a pump handle.

EXPT. 36.—Balance a light stiff lath upon an edge of a triangular block, or better, make a hole through its centre so that the lath will turn easily upon a stout nail fixed in a wall or blackboard. Hang a weight by means of a piece of thread upon the lath at any convenient distance on one side of the pivot or fulcrum, and balance it with a weight of the same amount on the other side. The distance of the weights from the fulcrum will be found the same in each case. Repeat the experiment with different weights on one side, and show by the results that, when the lath or lever is balanced,

$$\frac{\text{Weight on}}{\text{one side}} \times \frac{\text{Distance}}{\text{from fulcrum}} = \frac{\text{Weight on}}{\text{other side}} \times \frac{\text{Distance}}{\text{from fulcrum.}}$$

This principle applies to all levers, so that all you have to consider when thinking over the action of a lever of any kind, are the forces working in one direction and their distance from the fulcrum compared with the forces or resistances which oppose them and the distance of these from the fulcrum.

EXPT. 37.—For one of the letter balances in Fig. 18 substitute a triangular block arranged so that one end of the lath rests horizontally upon an edge of the block. The fulcrum is now at one end, as is the case with nutcrackers and wheelbarrows. Notice the reading of the

remaining letter balance when no weight is on the lath, and then place a weight at different distances from the fulcrum. This weight multiplied by its distance from the fulcrum expresses the turning power in one direction, and the increase of weight shown by the balance, multiplied by the distance from the fulcrum, shows the opposing action. Show that the principle referred to in the foregoing paragraph applies to levers of this kind whatever the positions of the weight and balance.

EXPT. 38.—Make a hole through one end of a light lath and place the lath upon the nail or pivot used in Expt. 36. Hold the lath horizontally by means of a spring balance attached to it by a piece of thread. Now suspend a weight from a point near the free end of the lath. Keeping the balance between the weight and the fulcrum, show that whatever the relative distances of the two from the fulcrum the principle already laid down holds good when the lath is kept horizontal. This class of lever is similar, as regards the distribution of forces, to sugar-tongs and ordinary fire-tongs.

It will have been seen from the preceding experiments that a small weight acting at a long distance from the fulcrum, or with a long arm, is able to balance a larger weight acting at the end of a shorter arm. There is a very definite relationship between the lengths of these arms and the weights: it is that the short arm bears the same proportion to the long one that the two weights bear to one another. The action of a lever may therefore be thus expressed:—

$$\text{Resistance overcome} : \text{Effort exerted} :: \text{Lever-arm of effort} : \text{Lever-arm of resistance.}$$

The Principle of Work.—It will be seen in the next chapter that work is measured by the product of a force and the distance through which a body is moved in the direction of the force. Now, in every case where such simple machines as the lever, pulley, inclined plane and screw are concerned, the work done by one set of forces is equal to that done by the other.

EXPT. 39.—Pivot a stiff lath at its centre as in Expt. 36, and place different weights on the two sides of the fulcrum. Arrange the weights so that the lath sets horizontally. Move the lath through a small angle and mark the lengths of the arcs described by the respective points of it to which the weights are attached. The lengths of the arcs will be found to bear the same proportion to one another as the arms at which the weights act, and this proportion will be the same as that between the weights themselves.

From the principle of work it follows that if a man, by exerting a force of 10 lbs. on one end of a crowbar, moves

100 lbs. at the other end, he has to exert his effort through 10 inches in order to move the weight one inch. In other words, what is gained in effect has to be made up by distance moved.

The Pulley.—A pulley is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame which holds the pulley is called the block.

EXPT. 40.—Attach a spring balance to one end of a piece of string. Make a loop in the other end and hang a weight from it. The spring balance, if correct, indicates the same weight as that suspended. Pass the string under a pulley as in Fig. 22, B*b*. The weight is now supported by two parallel portions of the string, and the tension of the string, as indicated by the spring balance, is only about one-half (neglecting the weight of the pulley) what it was before. Pass the string over a fixed pulley as shown by A*a* in the left-hand figure. The tension will be found the same as before.

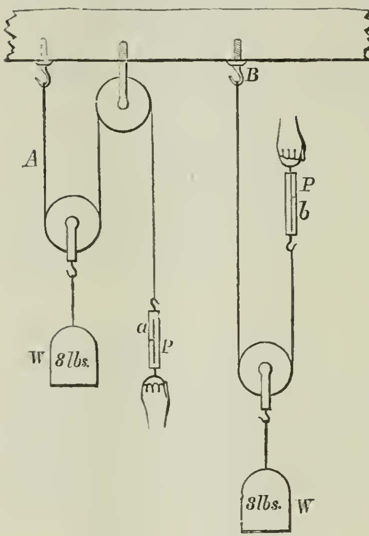

FIG. 22.—Actions of Pulleys.

This experiment shows that although a movable pulley, that is, one which can move up and down, reduces the effort which has to be exerted to support a given weight, a fixed pulley is of no advantage in that respect. The ratio of the effort exerted to the resistance or weight overcome is known as the *mechanical advantage* of a machine. One or two experiments will show more clearly how pulleys enable resistance to be advantageously overcome.

Use of a Single Fixed Pulley.—

EXPT. 41.—Fix a pulley as in Fig. 23. Pass a flexible cord over the groove, and hang a weight on each end of it. The weights have to be equal in order to balance one another.

The experiment shows that, with a single *fixed* pulley, no mechanical advantage is obtained. All that the pulley does is *to change the direction of the pull;* if one of the weights, for instance, is pulled down, the other rises. The pulley thus acts in the same way as a lever balanced at its centre ; the distance from the centre to the circumference, in other words, the radius of the pulley, being regarded as one arm of the lever. A pulley having a radius of three inches has therefore an equivalent lever-arm three times as great as one with a radius of one inch.

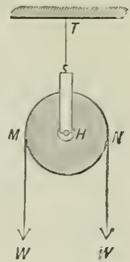

FIG. 23.—A Single Fixed Pulley.

Use of a Single Movable Pulley.—Advantage is gained by the use of *movable* pulleys. This can easily be proved.

EXPT. 42.—Arrange one fixed and one movable pulley as in Fig. 24. If a weight W is hung from the pulley, the weight P required to balance it will only be one-half of the weight. Repeat the experiment with several different weights and show that the mechanical advantage, that is, the resistance overcome divided by the effort exerted, is L in each case.

The fixed pulley, as has been already seen, is of no advantage in reducing the force required to raise a weight ; the advantage gained is derived from the use of the movable pulley. One half of the weight W is supported by the part of the string hooked to the beam, and the other half is supported by the part of the string which goes around the fixed pulley to the weight marked P. There are several different combinations of pulleys, but the principle exemplified by the foregoing experiments, namely, that every movable pulley reduces by one-half the effort required to support or raise a given weight, is utilised in them all. The more detailed description of the particular advantages of these systems is outside the province of Physiography.

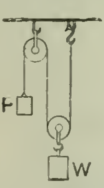

FIG. 24.—A Fixed and a Movable Pulley.

The Principle of Work Applied to Pulleys.—With pulleys, as with levers, there is neither loss nor gain of work. If, in any combination of pulleys, a force of 10 lbs. balance a force of 120 lbs.—the mechanical advantage (effort ÷ resistance)

thus being 12—the effort will have to be exerted through twelve feet in order to move the resistance through one foot. For it is an invariable rule that

$$\text{Effort} \times \frac{\text{the distance it}}{\text{acts through}} = \text{Resistance} \times \text{distance moved.}$$

The mechanical advantage of any system of pulleys can therefore be determined (1) by finding the relation between the weight moved and the effort exerted, or (2) by comparing the distance through which the effort is exerted with that through which the weight moves.

The Inclined Plane.—A plane in mechanics is a rigid flat surface, and an inclined plane is one that makes an angle with the horizon.

§ EXPT. 43.—Arrange a hinged board with a weight attached by elastic to the free end. Show that the tension is less when the weight rests on the board than when it is suspended freely.

The reason for the decrease of tension observed in this experiment will be best understood by applying the principle of the parallelogram of forces to the inclined plane. Suppose the stone G on the inclined plane shown in Fig. 25 to be at rest. It

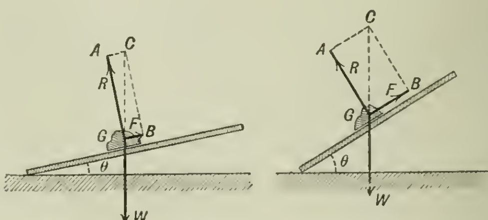

FIG. 25.—Parallelogram of Forces applied to the Inclined Plane.

is acted upon by three forces, namely, W, due to its weight, acting vertically downwards, F the tension of the elastic, and R the resistance acting at right angles to the plane. The weight acting downwards is thus kept in equilibrium by the two forces R and F acting upwards. The last-named force represents the effort exerted, and being one of two it is evidently less than the weight whenever the weight rests upon the plane. The two

diagrams in the accompanying figure show by means of the parallelogram of forces that the effort F, which has to be exerted to keep the weight in its place, increases as the inclination of the plane is increased. When the plane is vertical, the resistance R disappears, and the effort F becomes equal to the weight W.

To show the relation between the effort and the weight, the following experiment may be performed.

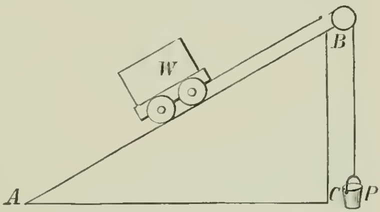

FIG. 26.—Experiment to illustrate the advantage of the Inclined Plane.

EXPT. 44.—Procure a toy carriage such as is on the plane in Fig. 26. Place some shot in it and find the total weight W of the carriage and shot. Attach one end of a string to the carriage after passing it over a pulley or smooth rod B, and fasten the other end to a small bucket or box P. Put sufficient shot in the box to balance the carriage. Find by several experiments the relation between W and P.

The experiment will show that the weight of the bucket and shot is less than that of the carriage and shot, and that the proportion which one bears to the other differs with different inclinations of the plane. There is a definite relation between this proportion and the slope of the plane on which the carriage travels. When the effort is exerted parallel to the plane, this proportion is as follows :—

$$\begin{matrix}\text{Weight} \\ \text{moved (W)}\end{matrix} : \begin{matrix}\text{Effort} \\ \text{exerted (P)}\end{matrix} :: \begin{matrix}\text{Length of} \\ \text{plane (AB)}\end{matrix} : \begin{matrix}\text{Height of} \\ \text{plane (BC).}\end{matrix}$$

This rule can also be deduced from the principle of work. If the carriage starts from A and moves to B, it is lifted through the vertical height BC. For this to take place, the effort will have to be exerted through a distance equal to the length of the plane AB. Therefore

$$\frac{\text{Weight}}{\text{Effort}} = \frac{\text{Distance through which the effort is exerted}}{\text{Vertical distance through which weight is lifted}}$$
$$= \frac{\text{Length of plane}}{\text{Height of plane}}$$

When the effort acts horizontally, the ratio which it bears to the weight is in the proportion which the *base* of the plane AC, bears to the height BC.

A wedge can be considered to be two inclined planes base to base, this double plane being forced forward by an effort exerted parallel to the direction of the base.

The Screw.—A screw may be regarded as an inclined plane wound around a cylinder.

§ Expt. 45.—Cut out of paper a right-angled triangle such as ABC (Fig. 27), and wind it around a lead pencil. The slant side of the

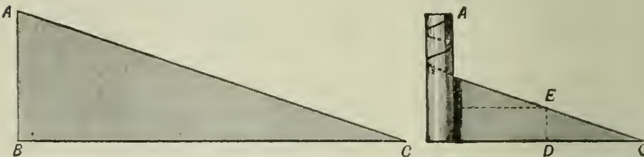

Fig. 27.—To illustrate the Principle of the Screw.

triangle forms a spiral upon the pencil, similar in appearance to the thread of a screw. Mark off from the point C a part of the base CD which will just go around the pencil, and draw the perpendicular DE. The small triangle CDE is similar to the large one and represents one turn of the screw-thread.

Comparing the screw-construction now with an inclined plane, it will be seen that

height of inclined plane represents distance between threads
base of ,, ,, ,, circumference of screw.

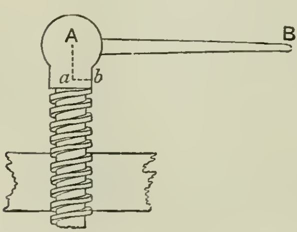

Fig. 28.—A Screw turned by a Lever.

The angle of inclination of the inclined plane is represented by the angle ECD, and this determines the *pitch* of the screw.

In considering the use of a screw, the resistance to be overcome can be regarded as a weight upon an inclined plane. With a screw such as is shown in Fig. 28, the effort acts in a

direction parallel to the base of the plane and under this condition

Weight : Effort :: Base of plane : Height of plane

Or expressing the proportion in the terms which apply to screws :—

$$\text{Resistance : Effort} :: \begin{array}{c}\text{Circumference}\\ \text{of screw}\end{array} : \begin{array}{c}\text{Distance between}\\ \text{successive threads.}\end{array}$$

When the force is applied at B, leverage is gained in the proportion of AB to *ab*, and so further mechanical advantage is obtained on this account. But, in order to advance the screw by a distance equal to that between two successive threads, the end of the handle B has to be turned through a complete circumference. This fact can be used to deduce the mechanical advantage of a screw from the principle of work. We get, in fact,

$$\frac{\text{Effort}}{\text{Resistance}} = \frac{\text{Circumference of circle described by power arm}}{\text{Distance between successive threads.}}$$

Chief Points of Chapter IV.

The Centre of Gravity of a rigid body is the point upon which the body could be supported or balanced ; in other words, it is the centre of the action of parallel forces produced by gravity acting on different parts of the body.

Principle of the Lever.—

$$\text{Effort} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum}\end{array} = \begin{array}{c}\text{Weight or}\\ \text{resistance}\end{array} \times \begin{array}{c}\text{Distance}\\ \text{from fulcrum.}\end{array}$$

Principle of the Pulley.—A pulley is a circular lever having its fulcrum at the centre. The force due to the weight pulling downwards is borne by two parallel forces, due to the tension of the string acting upwards, each with half the intensity of the downward force.

Principle of the Inclined Plane.—A weight on an inclined plane is pulled vertically down by gravity, and this pull is compensated by two forces, (1) that due to the resistance of the plane, (2) the effort exerted. The effort is thus always assisted by the resistance of the plane, unless the plane is vertical, and is, therefore, always less than the weight overcome.

Principle of the Screw.—A screw is an inclined plane wound around a cylinder. The distance between two successive threads, or the angle of the inclined plane by means of which the screw is considered to have been constructed, is the *pitch* of the screw. The Effort,

usually acting parallel to the base of the inclined plane, pushes the screw forward, and the resistance is similar to a Weight being pushed up an inclined plane.

The Principle of Work applies to every mechanical power; it is

$$\begin{array}{c}\text{Force}\\\text{or effort}\end{array} \times \begin{array}{c}\text{Distance}\\\text{of action}\end{array} = \begin{array}{c}\text{Weight}\\\text{or resistance}\end{array} \times \begin{array}{c}\text{Distance}\\\text{moved}\end{array}$$

Or Work done by Effort = Work done against Resistance.

Questions on Chapter IV.

(1) Describe an experiment to prove that the resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.

(2) How would you find experimentally the centre of gravity of a set square?

(3) Give a simple illustration of each of two different kinds of lever (1896).

(4) State briefly why it is that a lever may be used so that the force exerted by one end of it is greater than the force exerted upon the other end.

(5) What is meant by "the principle of work"? Apply the principle to the case of a lever.

(6) Describe the action of a single movable pulley in decreasing the force which has to be exerted to support a given weight.

(7) Show, by means of the parallelogram of forces, the action of an inclined plane when the effort is exerted parallel to the plane.

(8) Describe the relations between the inclined plane and the screw.

CHAPTER V

ENERGY

Work.—Newton's first law of motion teaches us that a body at rest is only set in motion by the action of a force upon it, and also that a moving body only changes the direction of its motion, or its speed, as a result of the action of a force. In the first case, the continued action of the force upon the body causes an acceleration in the body. In the second case, though we have every right to argue that a change of direction or velocity is the result of an external force, we cannot apply the converse statement and say that an external force acting upon a moving body causes a change of direction or of velocity, for in some instances the force may be entirely occupied in maintaining such motion in opposition to other forces acting upon it. Thus, when a ship is sailing with a uniform speed, the force of the wind is exhausted in maintaining this velocity by overcoming the resistance of the water.

When a force acts in either of these ways it is said to do *work*, that is, work is done by a force in setting a body at rest into motion and giving it a regularly increasing velocity, or by maintaining a uniform motion in opposition to the action of other forces. We may class all these forces acting in opposition to the force which is being considered under the inclusive name of *resistance*.

We shall thus obtain for our definition of work the following statement :—*Work is done by a force, either when it acts upon a body producing an acceleration in its velocity, or when it maintains a uniform velocity in a body in opposition to resistance.* A

little consideration will convince the student that all those instances of mechanical contrivances, which were considered in the last chapter, by means of which work is accomplished come within the scope of our definition, as well as all other cases when we say in ordinary language that work is done. Take, for instance, a horse drawing a heavy weight along a road. Here the force exerted by the horse is used up in overcoming the resistance due to the road. A man raising a mass from the ground overcomes the resistance due to the body's weight. A body falling from a height under the influence of the earth's attractive force has work done upon it, with the result that its velocity increases according to a uniform acceleration of 32·2 feet per second in every second.

Measurement of Work.—Referring to our definition of work it would seem as though we had two kinds of work to measure, viz., the *work of acceleration* and the *work against resistance*. But since we can make a force perform either of these kinds of work according to the conditions under which it acts, it is possible to measure either of them in the same units. An example will make this clearer. We can either allow a mass to drop from the hand and to move freely through the air with the uniform acceleration we have mentioned above until it reaches the ground; or we can attach the mass to a string, pass the string over a cylinder, and allow it to move towards the earth with a small uniform velocity—a result which can be brought about by applying the necessary friction between the cord and the cylinder, that is by applying a resistance. The final result brought about is the same under both sets of conditions; but in the first case the work is of acceleration, while in the second it is work against resistance.

Unless there is motion no work is done. If we could hold a weight upon the hand, keeping the hand quite still, no work would be done. The effort we are conscious of making when we perform this experiment is due to the slight incessant falling of the hand and its being put back into its original position again, thus necessitating the continual lifting of the mass through a small distance.

For practical purposes the unit of work which is adopted is *the work done in raising the mass of one pound through one foot*, and it is called the *foot-pound*. This is not a strictly constant unit, for it will be evident, in the light of what has been said about the weight of a body, that where the weight is greater the amount of work done will be greater. The unit of work will vary slightly in different latitudes in a precisely similar manner to that in which the weight of a mass varies.

It will have been noticed that the question of time does not enter into an estimation of the amount of work done. It is manifest that the same quantity of work is accomplished whether a day is spent in

raising a weight to a given height from the ground or only a minute. If we introduce the time taken to perform the work we begin to consider what is called the *power* of the agent. We should measure this power by the quantity of work the agent can perform in a given time; or *power is the rate of doing work* and is measured by the work done in a second. Thus, engineers use the expression *horse-power*, by which they mean the rate at which a good horse works. James Watt estimated this at 33,000 foot-pounds per minute, or 550 foot-pounds a second.

Generally, then, to find the amount of work performed by any force, we multiply the value of the force (expressed in suitable units) by the space through which it acts (using the corresponding unit in measuring this quantity also). The following simple application of the rule will familiarise the student with the method for employing it:—

How much work is done when an engine weighing 12 tons moves a mile on a horizontal road, if the total resistance is equal to a retarding force of 10 lbs. weight per ton?

The total resistance equals $12 \times 10 = 120$ lbs. weight, the distance traversed is 5,280 feet.

$$\therefore \text{ Work done} = (120 \times 5280) \text{ foot-pounds.}$$

Energy.—By the *energy* of a body we mean *its power of overcoming resistance or doing work.* All moving bodies possess energy. Moving air or wind drives round the sails of a windmill and so works the machinery to which the sails are attached; it drives along a ship, thus overcoming the resistance of the water. The running stream works the mill-wheel and the energy it possessed is expended in grinding corn. The bullet fired from a rifle can pierce a sheet of metal by overcoming the cohesion between its particles.

§ Expt. 46.—Stretch a piece of tissue paper over the top of an empty jam-pot. Carefully place a bullet on the paper and notice the paper will support it. Now lift the bullet and allow it to drop on to the paper. It is seen that the bullet pierces the paper.

§ Expt. 47.—Support a weight by a thin thread. Show that though the thread will support the weight at rest it will be broken if the weight is allowed to fall.

§ Expt. 48.—Show that a falling weight attached by a string to a spring balance extends the balance beyond the point which it indicates when the weight is at rest.

All these examples are cases of the energy of moving bodies, or the energy of motion, or *Kinetic Energy. Kinetic Energy is the energy of matter in motion.* All energy which is not kinetic is known as *Potential Energy.* It is capable of becoming

kinetic or active when the conditions become suitable. Imagine a mass raised from the ground and placed upon a high shelf. We know that to place it in this position we must expend a certain amount of work, which is measured by multiplying its weight by the height through which its mass is raised. Further, we know that just as soon as we release it from its position of rest, making it free to move, it will travel with an ever-increasing velocity until it reaches the ground. On the shelf the mass, by virtue of its position, possessed a certain amount of potential energy exactly equal to the work expended in placing it there.

Similarly, an ordinary dining-room clock, which is worked by a spring, affords us an example of potential energy. The wound-up spring possesses potential energy exactly equal to the amount of work done in winding it up. This potential energy is being continually converted into kinetic energy as it becomes unwound in working the clock.

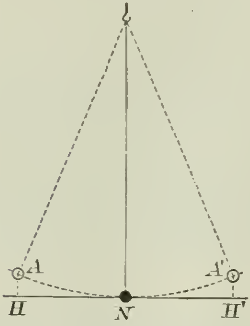

Fig. 29.—Pendulum in Oscillation.

The motion of a pendulum affords an interesting example of the two forms of energy. At the end of its swing, in the position A (*see* Fig. 29), the bob of the pendulum[1] possesses potential energy enough to carry it through half an oscillation, that is until it reaches its lowest position N, when the whole of the energy of position which it possessed at A is expended, as it can reach no lower position. But though it lacks potential energy, since it is a mass moving with the velocity it has gained in its passage from A to N, it possesses energy of motion or kinetic energy enough to carry it up to its next position of rest at A′—where the only energy it will have will be again potential. Through the next oscillation from A′ to A it will pass through just the same transformations again.

Forms of Energy.—A body may possess energy due to other causes than that of the actual motion of the body as a whole. When it is in rapid vibration, or when it is heated, or when it is electrified, it is endowed with energy in consequence of these conditions. But when a body is in rapid vibration it

[1] Some physicists regard the motion from A to A′ as half an oscillation.

gives out sound or becomes a sounding body, hence we may regard sound as a form of energy. We shall see that work may be done by the passage of heat from a hot body to a cold one, and, in consequence, heat is properly regarded as another form of energy. An intensely hot body emits light, hence it would seem that light and heat have a common cause and that we must also regard light, like heat, as a manifestation of energy. When a body is electrified it has the power of attracting unelectrified and certain electrified bodies also, and when such bodies are attracted as a result of this electrification we see that electrification must similarly be looked upon as still another kind of energy. Then, too, there is the force of attraction of magnetism, which is capable of accomplishing work and hence must likewise be looked upon as a form of energy. Chemical combination, again, gives rise to the development of heat, and resulting as it does from the chemical attraction of two, more or less unlike, forms of matter, we shall be right in regarding chemical attraction as another kind of energy. *In addition to the energy of moving bodies we have energy manifested as sound, heat, light, electrification, magnetism, and chemical action.*

Bearing this in mind, it will perhaps assist the student to grasp the enlarged conception of energy which is here presented to him, if he regards energy as being a *capacity for producing physical change.*

Heat as a Form of Energy.—Heat was not always regarded in this way. It was originally thought to be a fluid called Caloric, and it was supposed that a piece of hot iron differed from a cold piece in having entered into some sort of union with this fluid. But, since the experiments of Rumford, we can no longer doubt that heat is not material, but a form of energy. Rumford boiled water by the heat developed by the friction between two metal surfaces which he rubbed together; and he found that the amount of water he could bring to the boiling temperature depended only on the amount of work he expended in rubbing. Since he could obtain an indefinite amount of heat from two definite masses of metal, it was quite clear that heat could not be matter, which, as we have seen, cannot be created. Davy made the truth even clearer by obtaining heat enough to melt ice by simply rubbing two pieces of this solid together. They were both cold or without caloric;

and since heat could be obtained by rubbing even these together, it was quite certain that heat could not be a fluid. Joule went a step further and measured the amount of work which must be done to obtain a given quantity of heat; or, as we say, he measured the *mechanical equivalent of heat*.

Some examples which will be familiar to the student will provide him with proofs of the statement that heat and work are convertible. When a brake is applied to the wheels of a train, as it stops at a station, it is a common thing to see sparks fly. The resistance of friction which overcomes the motion of the train causes a sufficient amount of heat to be developed to raise the particles of steel which get rubbed off to a red heat. By continually hammering a piece of iron on an anvil it can be made too hot to hold in the hand.

The following experiments show that heat appears when motion is destroyed:—

§ Expt. 49.—Procure a piece of lead in the form of a sphere (about the size of a marble) with a neck or hook upon which a piece of string can be fastened. Tie a piece of string firmly to the neck, and while holding the string strike the sphere several times smartly on an iron plate. Test the temperature of the ball before and after the experiment by a thermopile and galvanometer.

§ Expt. 50.—Hammer a piece of lead, or saw wood, and test the temperature of the lead or saw before and after the experiment.

§ Expt. 51.—Rub a brass nail or button on a wooden seat, and notice its increase of temperature.

When we rub a lucifer match along a rough surface the heat into which the work is converted is enough to ignite the match. In all these cases mechanical work is converted into heat. The converse is true also, heat is convertible into work. In the steam-engine the heat of the furnace changes the water in the boiler into steam. The steam forces the piston along the cylinder, and this movement of the piston in a straight line is converted into the circular motion of a fly-wheel; or is used, through the intervention of suitable mechanism, in pumping water or performing some other kind of work. The steam which enters the cylinder is hotter than that which leaves it for the condenser. The difference of heat is found to be equivalent to the work which the engine has done.

We can show by a simple experiment that heat often disappears when motion is produced.

§ Expt. 52.—Allow air, which having been compressed into a cylinder has again assumed the temperature of the air, to come in contact with a thermopile or other delicate means of measuring changes of temperature. Notice the cooling of the compressed air when allowed to escape.

Before leaving the consideration of heat in this connection it will be well to point out that the expression "heat" is used in speaking of two manifestations of energy—first, there is what is called *Radiant Heat*, which passes from one place to another without the intervention of a

material medium of an ordinary kind, as in the passage of the heat of the sun to the earth, or that of the fire to our bodies when we stand in front of it ; and secondly, that heat which is due to a confused, more or less rapid, movement of the molecules of a body, dependent upon their degree of hotness or coldness. This second manifestation is what is ordinarily called Heat, and the form of energy to which we have referred in this paragraph.

The Energy of Radiant Heat and Light.—We shall see more fully in our chapter on Radiation the reasons we have for regarding these as being of the same nature. We refer under this heading to those forms of energy which travel through space where, as we know, there is no air to convey them in the way in which sound is transmitted. But in order to understand the transmission of these forms of energy it is necessary to imagine the existence of a medium which is referred to as the luminiferous ether, or more shortly as the "ether." Certain experiments and observations by different investigators leave no doubt of the existence of this medium, vibrations in which cause light and radiant heat. Sound passes through air by the to and fro vibration, in turn, of the air particles, in the form of a *wave* as it is called. So radiant heat and light pass through the ether by the successive motions of the constituent molecules of the ethereal medium.

This takes place with astonishing quickness, for light travels about 186,000 miles per second, or something like $7\frac{1}{2}$ times round the earth in this small interval of time. Nor does the ether fill inter-stellar space alone, for it must exist in the interstices (*see* p. 3) of those bodies through which radiant heat and light can pass, or how else can light pass through a transparent body, or radiant heat through substances like rock-salt?

It is interesting to consider that since radiant energy passes by means of the vibration of the ether, each molecule of the medium moves in its turn, and that the energy in its passage through space is alternately potential and kinetic. The student may at first be disposed to look upon the energy of radiation as much less powerful than other kinds of energy ; but if he consider for a moment, he will see that all the energy which reaches us from the sun assumes this nature in its passage, and becoming absorbed by the earth, gives rise eventually to nearly all the energy which we know.

Radiation can be converted into work, but in a less direct manner than is the case with ordinary heat. It must first be absorbed and heat some material body causing its molecules to oscillate in the manner we

have described. This form of heat, we have seen, has a mechanical equivalent, and we can fairly argue that, if the whole radiation is absorbed, the mechanical equivalent of the absorbed heat is an exact measure of the energy of the radiation.

Energy of Electrification and of Electricity in Motion.—We are careful not to speak of electricity as a form of energy, for whatever electricity may be it certainly is not energy. Though it would be very interesting to discuss the nature of electricity it does not come within the scope of our subject. The following experiment will show that we are right in regarding electrification as a manifestation of energy:—

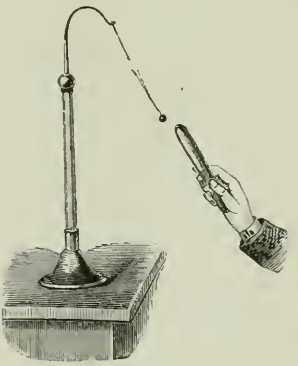

FIG. 30.—Electrical Attraction.

§ EXPT. 53.—Suspend a pith-ball by a silk thread to a bent wire, as is shown in Fig. 30. Rub a rod of sealing-wax with fur and touch the pith-ball with the rod. Notice that after the contact it is impossible to make the ball come to the rod. They *repel* one another.

EXPT. 54.—Having touched the pith-ball with the rod of sealing-wax, which has been rubbed with fur as in the last experiment, bring near to it a rod of glass which has been rubbed with dry silk. Notice that the ball is *attracted* towards the glass rod.

What is the significance of these experiments? In both cases the pith-ball moves through a certain distance under the influence of a force, in one case of repulsion, in the other of attraction, and in consequence work is done. Under certain circumstances, as in the discharge of a Leyden jar, the energy of electrification becomes manifest in the form of a vivid spark and a slight explosive sound.

Electricity in motion constitutes what is known as the *electric current*, and of its capability of doing work the student has abundant evidence in the heat and light of an incandescent electric lamp, where the passage of the current through a wire, which offers considerable resistance to its passage, causes the

wire to become sufficiently hot to be utilised as a source of light.

It will be very instructive to consider briefly the case where the electric current is formed as the result of chemical action in a battery, and thence passed by wires to a lamp of the kind mentioned. This is the ordinary condition of things as already described ; but imagine the lamp left out and the battery made to work simply through an ordinary copper wire which presents little resistance. The current has no work to do beyond heating the wire, and the energy of the current is almost wholly expended in heating the liquids and other parts of the battery, which is of course a very undesirable waste of energy.

§ EXPT. 55.—Show the motion of a magnet produced by an electric current in a wire held over it.

Instances of the conversion of the energy of the electric current into mechanical work will doubtless have come under the student's attention.

Other forms of energy can be converted into that of electrification and of electricity in motion. If we heat certain crystals, *e.g.*, tourmaline, it is found that it becomes electrified, one part of the crystal exhibiting electrification of the kind developed when sealing-wax is rubbed with fur, another exhibiting the kind obtained by rubbing glass with silk.

Heat can give rise to electric currents. If we solder a piece of the metal antimony to a piece of the metal bismuth and apply heat to the junction, it is found that an electric current passes from the bismuth to the antimony.

Energy of Chemical Action.—EXPT. 56.—Place a small piece of dry phosphorus[1] on a plate, and a short distance from it a few grains of solid iodine. Nothing happens. By means of a glass rod push the piece of phosphorus on to the iodine, and notice that when they come into contact the phosphorus inflames and dense fumes are formed which, as will be understood after reading the chemical section of this book, is a compound of phosphorus and iodine.

EXPT. 57.—Call attention to the heat of the flame of the laboratory burner where certain chemical actions are going on, which are described on p. 14.

In speaking of heat as a form of energy we took the example of the work done by an engine as the result of the heat from the furnace ; but we can now push our inquiry a step further back. What causes the heat of the furnace? Evidently the burning of the coal, which, as we shall learn, is nothing more than chemical action. The coal enters into a chemical combination with one of the constituents of the atmosphere, and in doing so, heat is evolved, as it is, indeed, in all cases of chemical combination.

[1] See precautions necessary in using phosphorus on p. 130.

But as we shall soon have occasion to study many cases of chemical action, we need not spend much space over the matter here, though it must be pointed out that, just as in all the other instances of energy we have studied, not only is it true that chemical action can be converted into other forms of energy, but also that it can result from these other forms. The experiment on p. 110 shows that copper and sulphur will remain side by side indefinitely without combining so long as they remain at the ordinary temperature of the air, but as soon as heat is applied and they become warmed to a certain extent, they combine together. Light can be made to bring about chemical action, as it does in the case of the exposed photographic plate. Electric separation or the energy of electrification also causes chemical action, as will be seen later.

Transformation of Energy.—We have abundantly learnt that one kind of energy can cease to exist in that particular form, and can assume another condition. We have seen that the energy of moving bodies can give rise to sound and heat; that heat can be changed into the energy of moving bodies, electric currents, and chemical action. Indeed, one form of energy can assume almost any other form. The general tendency of all forms of energy is gradually to get converted into heat. When this change has become complete and all the energy of the universe exists as heat at the same temperature, there will be no further transformations possible. Consequently no work of any kind will be possible, which means there will be no life, no movement of bodies from place to place—a still dead world in fact.

Conservation of Energy.—We have seen that matter cannot be destroyed; we have now to learn that *energy is indestructible.* The total amount of energy in the universe remains the same. One form may be changed into another, but we can create no new energy. We may be unable to trace and account for some of it in the numerous transformations which it undergoes, but we are sure, from many considerations, that if our methods of experiment were only refined enough, we should be able to account for the whole amount.

The great source of energy in the solar system is the sun. It is from the sun that we are continuously receiving streams of energy in the form of radiation, which are continually assuming

the various other forms of energy we have considered. Returning once more to our steam engine, we have traced back the work it does to the chemical combination of the coal with the oxygen of the atmosphere. Or putting the case in another way, we have seen that there exists a certain amount of potential energy in the coal which is capable of becoming kinetic as soon as the temperature at which it can combine with oxygen has been reached. Whence comes the potential energy of the coal? As we shall study in detail later, coal results from the compression of vegetable material which lived and flourished on the earth ages and ages ago. This vegetable material formed the tissues of mosses and other similar plants, which in the presence of sunlight have the power, by virtue of the green colouring matter they contain, of decomposing one of the gases of the atmosphere, carbon dioxide, splitting it up into its elements, carbon and oxygen, reserving the former for themselves and returning the latter to the air. This carbon unites with the elements of water contained in the plants forming compounds which build up the tissues of which the plant is constructed. The tissues of the plant represent from our point of view the work done in splitting up the carbon dioxide by absorbing the energy of radiation. They still represent this energy when they have assumed the condition of the coal, and it is in this sense that coal is poetically referred to as "bottled sunshine."

If the earth receives so great an amount of energy from the sun, it is easy to understand that the total quantity of energy which emanates from our luminary must be enormously greater. But this radiation from the sun's surface is continually going on; that is, the sun is constantly losing energy, and this cannot go on indefinitely without the loss being made good. How is the energy of the sun maintained? It has been suggested that the heat generated by the impact of the meteorites which fall upon the sun in great numbers is capable of accounting for this energy; and that in addition to this a slight shrinkage of the sun's mass in cooling evolves a large amount of energy. But interesting as this subject is we cannot pursue it further here.

Chief Points of Chapter V.

Work is the act of overcoming resistance, or causing change of velocity.

The Principle of Work.—Work is done by a force when the point of application moves through a certain distance.

Work done = force × distance.

A Foot-pound is the work done when a force of one pound is exerted through a distance of one foot in the direction of the force.

Power, or the rate of doing work, is measured by the number of foot-pounds produced in a given time. A horse-power is equal to 33,000 foot-pounds per minute.

Energy is the ability to do work.

Energy

Kinetic,	Potential
due to motion as shown by a moving cannon-ball and a flowing river.	due to position, as a mass at the top of a tower and a wound-up spring.

Manifestations of Energy.

- *Sound*, produced by vibrations of material substances.
- *Heat*, produced by motions of molecules.
- *Radiation*, due to vibration set up in the ether, and producing the effects of radiant light and heat.
- *Electrification*, evidenced by the action of electrified bodies upon one another.
- *Electricity in motion*, as in the electric current, which can be transformed into light, heat, or motion.
- *Chemical action*, used to produce light and heat when a fire burns, and to produce motion in a gas-engine.

Conservation of Energy.—Energy is never lost, but only changed in form, and whatever transformations take place, the sum total of kinetic emergy and potential energy remains the same.

Questions on Chapter V.

(1) Define the terms "energy" and "cohesion," and give examples of the action of chemical, magnetical, and gravitational attraction (1893).

(2) In the case of a shot fired at a target, state (*a*) why the velocity of the shot changes; and (*b*) why the target is made hot where the shot strikes it (1890).

(3) Define work, and describe an experiment to prove that a falling ball is capable of doing work.

(4) What is the difference between kinetic energy and potential energy?

(5) Describe an experiment to prove that energy due to visible motion can be transferred from one body to another.

(6) What proof can you adduce that energy of visible motion can be transformed into heat?

(7) How do you account for the fact that heat generally appears when motion is lost?

(8) Describe an experiment which indicates that "Heat is a form of Energy."

(9) How would you prove that "when bodies are electrified they are endowed with energy and can produce motion and heat"?

CHAPTER VI

HEAT AND TEMPERATURE

The words "heat," "temperature," "hot," and "cold," have already been used, and it is time that we learnt exactly the meanings attached to these expressions. In regarding heat as a form of energy we found it necessary to speak in somewhat vague terms of its nature, but the student will by studying the properties of heated bodies, and by learning how it is measured, be in a position to form a much clearer conception of what constitutes heat.

Hot and Cold Bodies.—

Expt. 58.—Arrange three basins in a row, into the first put water as hot as the hand can bear, into the second put luke-warm water, and fill the third with cold water. Place the right hand into the cold water, and the left into the hot, and after half a minute put both quickly into the luke-warm water. Notice that the left hand feels cold and the right warm while in the same water.

It is evident, therefore, that our feelings are but poor judges of the heat condition of a body. Similarly, by touching a succession of things in a room, say the marble mantel-piece, the fender, the back of a chair, the hearth-rug, we obtain a succession of sensations, the first two we say are cold, the chair-back not so cold, while the rug feels quite warm, and yet they are one and all under the same conditions and there is no reason why they should not be heated to the same extent. The explanation of these different sensations is really very simple. In all those cases where the hand *receives heat* we feel the sensation of warmth, while in those where the hand *gives out* heat we say

the body is cold or cool. Fig. 31 will enable the student to remember this. Now we see why the fender feels colder than the hearth-rug. The fender takes more heat from the hand than the hearth-rug, and it does so because it is a better *conductor of heat*. We shall do well to consider this expression a little. Put one end of a poker in the fire and hold the other. Soon the poker begins to feel warm, and as time goes on it gets warmer and warmer, until at last you can hold it no longer. Heat has passed from the fire along the poker, or has been *conducted* from the fire by the poker. *The process by which heat passes from one particle of a body to the next is called conduction, and the body along which it passes is known as a conductor.* Those bodies which allow heat to pass along them in this way readily are spoken of as good conductors, and it is the possession of this power by the fender which makes it feel cold to the hand. It is evidently necessary, therefore, to obtain some surer measurer of the heat condition of a body than our hands.

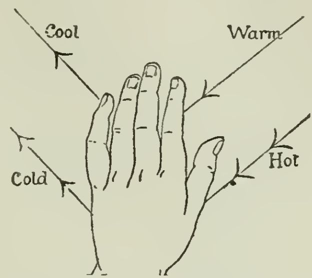

FIG. 31.—Hot and Cold Bodies.

Temperature.—From the use of this word in earlier parts of the book, where it seemed impossible to substitute another and still be accurate, the student will have some idea of what the word signifies. It is not heat. It is only a state of a body, for the body may be cold one minute and hot the next. A hot body is one at a high temperature, a cold body one at a low temperature. If a hot body and a cold body be brought into contact there is a passage of heat from the hot one to the cold until they are both of the same degree of hotness or coldness. Now in this last sentence substitute "at a high temperature" for "hot," and "at a low temperature" for "cold," and we shall see our way to a definition of temperature; thus, if a body at a high temperature and one at a low temperature be brought into contact there is a passage of heat from the

former to the latter until they are both at the same temperature. Hence, we can define temperature *as a condition of bodies that determines which of two bodies when placed in contact will part with heat to the other.*

Evidently it is analogous to the level of water, for we have learnt that if two cisterns containing water at different levels be put in connection there will be a flow of water from the one where the water stands at the higher level to the other until they assume the same level.

Effects of Heat.—The effects of heating a body can be classed under three heads—(1) change of size, (2) change of temperature, (3) change of state.

The change of size which a body undergoes is spoken of as the amount it *expands*; or heat is said to cause *expansion* in the body. This expansion is regarded in three ways. When we are dealing with solids, we speak of expansion in length or linear expansion, expansion in area or superficial expansion, and expansion in volume or cubical expansion. In the case of liquids and gases we are concerned only with their cubical expansion.

Change of temperature of course means simply that the effect of an addition of heat is to make the body get hotter and hotter, while a subtraction causes it to become colder and colder.

Change of state includes changes in the physical condition known as liquefaction or becoming liquid, and vaporisation or becoming converted into vapour. Thus, if we heat ice it first liquefies or becomes water, and is then vaporised or becomes steam.

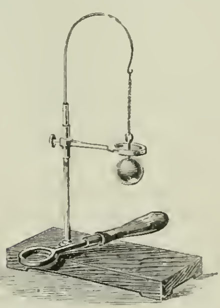

FIG. 32.—The Expansion of a Solid.

Change of Size—Expansion.—

EXPT. 59.—Take a metal ball suspended by a chain as shown in the figure, and suspend it by the side of a metal ring, through which it passes easily, or fits loosely. Heat the ball in a laboratory burner for a few minutes, and then try to drop it through the ring. It is too large and rests on the ring. Now allow it to cool slowly and notice that after a short time it gets smaller and will slip through quite easily.

EXPT. 60.—Procure a 4 oz. flask and fit it with a cork. Bore a hole through the cork and pass through a long glass tube which fits tightly. *Fill* the flask with water coloured with red ink. Push the cork into the neck of the flask and so cause the coloured water to rise up the tube. See that there is no air between the cork and the water. Now dip the flask in warm water, and notice that the liquid gets larger and rises up the tube. Take the flask out of the warm water, and see that the coloured water gets smaller as it cools and that it sinks in the tube. See Fig. 33.

EXPT. 61.—Procure a well-made paper bag and tightly tie a piece of tape round the open end. Hold the bag in front of the fire and notice that the air inside gets larger and inflates the bag.

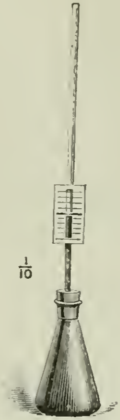

FIG. 33.—The Expansion of Liquids.

These experiments convince us that all bodies, whatever their physical condition, solid, liquid, or gaseous, get larger when heated and smaller when cooled. Now if they get larger their volume increases, and as the amount of matter in them, *i.e.*, their mass, remains the same, from what we have learnt about density it is clear that it must become less, or *bodies get lighter, bulk for bulk, when they are heated.* The converse holds true, *if they get cooler their density, bulk for bulk, gets greater.*

Other Experiments to Illustrate the Expansion of Bodies when Heated. § EXPT. 62.—Solder together side by side a brass wire and an iron wire, each about two feet long. Hammer the compound wire straight, and notice how it bends when heated.

§ EXPT. 63.—Fuse a piece of platinum wire through the side of a glass tube, and notice that the glass does not crack on cooling. The platinum and glass expand about the same amount for an increase of temperature.

§ EXPT. 64.—Fit with corks the necks of three 4 oz. flasks. Fit tightly into the corks three narrow glass tubes open at both ends. Fill the flasks with water, alcohol, and oil of turpentine respectively. Push in the corks till the liquid stands in each tube at the same height. Put all three flasks to the same depth into a vessel of warm water. Notice that the expansion of the glass causes a momentary sinking of the liquids; that ultimately the expansions are very different.

§ Expt. 65.—Fit a 2 oz. flask with a tight cork through which a tube passes, the upper end of which is bent down and then up at the end. Clamp the flask so that the end of the tube dips under water in a basin. Fill a test-tube with water, and invert it over the end of the tube. Warm the air in the flask, and collect the expelled air in the test-tube.

§ Expt. 66.—Fit tightly a cork, through which a straight tube passes, into the neck of a 2 oz. flask. Turn over and pass the tube through the cork in the neck of a wide-mouthed bottle, containing coloured water. Warm the flask with the hand so as to expel some of the air, and let the liquid rise in the stem. This constitutes an *Air Thermometer*.

§ Expt. 67.—Fasten two flasks together (air-tight) by a tube bent six times at right angles and containing some coloured liquid in the middle bend. Show that the liquid moves if one flask is warmed more than the other.

Change of Temperature—Its Measurement.—The change of size which bodies experience when heated can evidently be made to provide us with a method of measuring the change of temperature which bodies undergo. If we can find some form of matter which expands regularly as it is heated, the increase in volume which results can be taken as a measure of the change of temperature. Thus, using the arrangement in Expt. 60, if we notice that the coloured water in the tube rises through a certain number of inches for a certain change of temperature, we can look upon this rise of the level of the water in the tube as an equivalent of a certain change of temperature, and we can be sure that if as the result of its contact with any other body, the liquid rises through this amount, that the body with which it is in contact has caused it to experience the change of temperature to which it is equivalent, and that the body is at the temperature represented by the higher level of the water. An arrangement of this kind is, then, a "temperature measurer," or, as it is always called, a *thermometer*.

It has been found by a long series of experiments that liquids expand much more than solids for a given change of temperature, and that gases again expend still more than liquids. Further it has been observed that *all gases expand to the same amount for a given change of temperature*.

Since gases expand so much more than liquids, thermometers made in such a way that some gas is the form of matter which expands will be very much more accurate than liquid ther-

mometers. Instruments are actually made in which air is used. They are called *air-thermometers*, and are very accurate indeed.

Thermometers.—*Choice of Materials.*—(1) *Liquid.* The property of substances which we have now considered is made use of in the construction of temperature measurers or thermometers in the following way. First we have to choose a suitable substance, and generally one of two liquids is selected, depending upon the particular purpose to which the thermometer is to be put. If it is to be employed for the measurement of very low temperatures, we shall use alcohol in our thermometer since it is a liquid which has not yet been frozen. If we wish to measure higher temperatures, alcohol would be unsuitable since it boils at a temperature of 78° C.[1] which is, as we shall see, considerably lower than the boiling point of water. For such higher temperatures mercury is used because it does not boil until the temperature of $357\frac{1}{4}^\circ$ C. is reached. But though its boiling point is high enough to make it very valuable for the purpose named, it cannot be used for measuring very low temperatures as at -40° C. it solidifies.

There are other reasons for selecting mercury in addition to the important one we have just given. It is a liquid whose level can be easily seen; it does not wet the vessel in which it is contained; it expands a considerable amount for a small increment of temperature; it is a good conductor of heat, and consequently it very quickly assumes the temperature of the body with which it is placed in contact. Very little heat is required to raise its temperature, and there is therefore very little loss of heat due to warming the thermometer.

(2) *The Tube.*—Liquids, as we know, must be contained in vessels to keep them together. Consequently, the liquid we have chosen will have to be enclosed in some sort of case. For this purpose a glass tube is used and some care must be exercised in selecting one. It should have a narrow bore, so that a given expansion of the liquid shall be spread over a considerable distance. The bore must be of equal size, or as nearly as we can get it, in every part, and as it is impossible to get one which is quite regular it is usual for very accurate work to *calibrate* it, *i.e.*, to find the volume of each part of the bore.

Construction of a Thermometer.—Having selected a suitable piece of thermometer tubing a bulb must be first blown on one end. The glass is melted at this end and allowed to run together and so close up the bore, and while the glass is still molten, air is blown down the tube from the other end, keeping it moved round, so that the bulb is symmetrically placed with reference to the tube. The bore of the tube is so fine that it is impossible to pour the liquid down it; some other plan must therefore be adopted. The tube is warmed and inverted in some of the liquid. Let us suppose we are using mercury.

[1] These numbers will be understood after the section on the graduation of a thermometer has been read.

Warming the tube makes the air inside it get larger, and of course some is driven out. As the tube cools the mercury is forced in by the weight of the atmosphere to fill the place of the expelled air. By repeating this alternate process of warming and cooling, under the circumstances we have described, enough mercury is soon introduced into the tube. The next step is to seal up the tube, leaving no air above the mercury; to do this the bulb is heated to a temperature slightly higher than we shall want our thermometer to register, the mercury expands, and when it has reached the top of the tube, the end is closed by directing a blow-pipe flame against it. This method of closing a tube and keeping the air out is called *hermetically* sealing it. The thermometer at this stage should be put on one side for some days at least, in order that it may assume its final

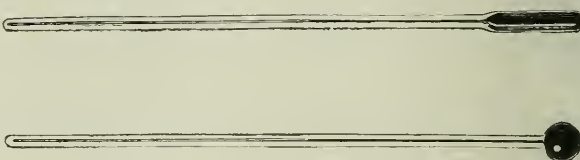

FIG. 34.—Thermometers before Graduation.

size, which it does very slowly indeed. The thermometer will now look like one of those in Fig. 34, according to the shape of the bulb which has been blown.

Graduating the Thermometer—Fixed Points.—In the graduation of a thermometer the plan always adopted is to choose "two fixed points" from which to number our degrees of temperature. The most convenient lower fixed point we can get is the temperature at which ice melts, or water freezes, for this is always the same if the ice is pure, and remains the same as long as there is any ice left unmelted. The "higher fixed point" chosen is that at which pure water boils at the sea-level. We have to make this stipulation, for the boiling point of a liquid is altered when the pressure is changed, being raised if the pressure is greater and lowered if the pressure is less.

When the water boils the temperature of the steam is the same as that of the water, and remains so as long as there is any water left. The lower fixed temperature we refer to as the "Freezing point of Water," the higher as the "Boiling Point."

Marking the Freezing Point.—For this purpose an arrangement like that shown in Fig. 35 is very suitable. The funnel is filled with pounded ice, which before powdering had been carefully washed; or snow might, if more convenient, be used. The glass dish catches the water which is formed from the melting of the ice or snow. We make a hole in the pounded ice by thrusting in a pencil or glass-tube about the size of the thermometer, and into this hole we put the thermometer and

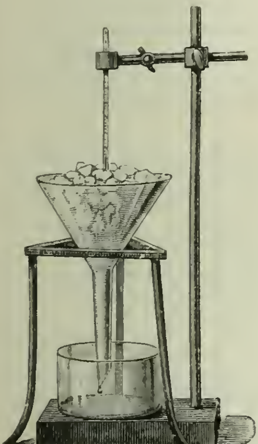

FIG. 35.—Marking the Freezing Point.

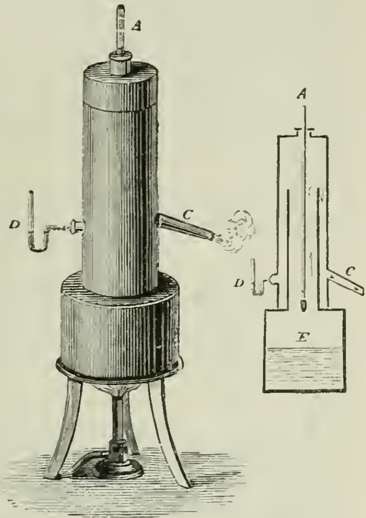

FIG. 36.—Marking the Boiling Point.

support it so that the whole of the mercury is surrounded by the ice or snow. The arrangement is left for about ten or fifteen minutes, until it is quite certain that the tube and mercury are at the same temperature as the melting ice. When this is so the tube is raised until the mercury is just above the ice, and a fine scratch made with a three-cornered file on the tube at the level of the mercury.

Marking the Boiling Point.—The apparatus used for doing this will be readily understood by examining Fig. 36,

Water is contained in the cylinder E, which is of much smaller diameter towards the top, where it is open in the way the drawing shows. Over this smaller open cylinder is placed a larger one, which rests on the larger cylinder containing the water, and is provided with three openings—one at the top A through which to pass the thermometer, one at the side C to allow superfluous steam to escape, and one for the introduction of a bent tube containing mercury, for indicating whether the pressure inside the apparatus is the same as that of the surrounding air, and which is known as a *manometer*.

The apparatus is arranged as shown in the left-hand figure, and the water in E boiled. Steam is generated, and circulates as shown by the arrows. The thermometer is exposed to the steam until it has taken the temperature of the boiling water, and the level of the mercury is then scratched on the tube.

Choosing the Scale.—Some value must now be given to these two fixed points, and of course they can be called anything the maker likes, but for the sake of comparing one man's observations and experiments with those of other people it is most convenient to graduate all thermometers in the same way. The thermometers of this country are divided up in two ways—(1) the Centigrade scale, (2) the Fahrenheit scale.

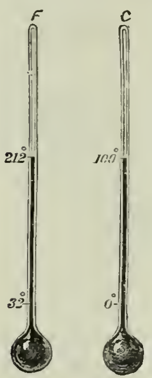

FIG. 37.—The Fahrenheit and Centigrade Scale.

The Centigrade Scale.—Here the freezing point is called *zero* or *no degrees*, written 0° C. The boiling point is called *one hundred degrees Centigrade*, and is written 100° C. The space between these two limits is divided into 100 parts, and each division called a *degree Centigrade*.

The Fahrenheit Scale.—On thermometers marked in this way the freezing point is called *thirty-two degrees Fahrenheit*, written 32° F., and the boiling point *two hundred and twelve degrees Fahrenheit*, written 212° F. The space between the two limits is divided into 180 parts and each division is called a *degree Fahrenheit*. The reason of this difference is interesting. The physicist Fahrenheit, after whom the thermometer is named, got as he thought, a very low temperature, by mixing common salt with the pounded ice when measuring the lower fixed point, and he imagined that he had got the lowest temperature which could be reached, and called it zero. Of course he was wrong, and his mistake has brought about two ways of measuring temperatures.

Conversion of Scales.—It should be clear from what we have said that the interval between the boiling and freezing points, that is the same temperature difference, is divided into 100 parts on the Centigrade scale and 180 parts on the Fahrenheit, and consequently 100 Centigrade degrees are equal to 180 Fahrenheit degrees, which is the same as saying one degree Centigrade is equal to nine-fifths of a Fahrenheit degree. Or one degree Fahrenheit is equal to five-ninths of a degree Centigrade.

$$100^\circ C. = 180^\circ F. ; \therefore 5\,C. = 9\,F. \therefore C. = \tfrac{9}{5}F. \text{ or } F. = \tfrac{5}{9}C.$$

In converting Fahrenheit readings into Centigrade degrees, we must subtract 32 (because of what has been said of the freezing point on the former scale) and multiply the number thus obtained by 5 and divide by 9. To change from Centigrade to Fahrenheit, multiply the former reading by 9 and divide by 5 and add 32 to the result.

When it is necessary to refer to temperatures lower than the freezing point of water a minus sign is placed before the temperature, thus three degrees below the freezing point of water on the Centigrade scale is written $-3^\circ C.$

Maximum and Minimum Thermometers.—It is often desirable, not only to know the present temperature, but

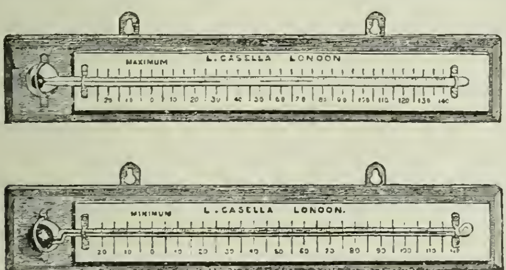

FIG. 38.—Maximum and Minimum Thermometers.

also the highest temperature which has been reached since the thermometer was last read. For example, in weather reports it is usual to record the highest temperature which has been reached during the day, and it is manifestly impracticable to continuously watch the thermometer with a view to determining this. By a simple device the thermometer itself can be made to record this reading. The arrangement by which this is accomplished constitutes a *maximum thermometer*, as shown in Fig. 38. In one kind of instrument there is introduced into the stem

of the thermometer (before sealing it), above the mercury, a thin piece of iron wire which works loosely in the tube. When the mercury expands it pushes this piece of wire before it and on contracting leaves the wire at the highest place to which it has been pushed. The reading indicated by that end of the wire nearest to the mercury is the maximum temperature which has been reached. To set the thermometer again the piece of wire is drawn back to the mercury by the attraction of a magnet which hangs near the thermometer for this purpose. This is only one of many devices which have been suggested and used for this purpose; the student should refer to one of the larger books on heat for an account of the others.

In a precisely similar way arrangements have been devised for measuring the lowest temperature reached during the night or any other period. They are known as *minimum thermometers*. As we have seen, when measuring low temperatures it is general to use an alcohol thermometer, and these can easily be made to themselves register the lowest temperature experienced. Into the stem of the thermometer a marker is introduced as is done with maximum thermometers, but the marker is of a different kind. It is either a fine capillary tube or a black index, shaped something like a dumb-bell. When the temperature falls the alcohol contracts, and the marker is dragged back with the liquid in consequence of the adhesion which subsists between the two materials. When the temperature rises again, the index remains stationary, the alcohol flowing round or through it according to the kind of marker, but causing it to undergo no displacement. The end of the marker farthest away from the bulb will indicate the lowest temperature which has been reached.

Thermometer for Measuring the Intensity of the Sun's Heat.—Thermometers of this kind are often called *solar radiation thermometers*. The construction and use of such instruments are easily understood. A maximum thermometer is enclosed in a much larger tube with a globe attached. All air is taken from the glass envelope and the thermometer rests therefore *in vacuo*. The bulb and part of the stem of the thermometer are covered with lamp-black, which is a substance that absorbs all heat radiation, such as sunshine, falling upon it. The apparatus is supported at a height of three or four feet from the ground in a horizontal position. In the sunshine the

heat rays which fall upon the lamp-black are absorbed and go to raise the temperature of the mercury, and since the thermometer is *in vacuo* there can be no loss of heat due to the production of air currents round it. In the immediate neighbourhood an ordinary thermometer is exposed, and the difference between the readings of the two instruments, which is generally something like from 10 to 20° C., is an index of the intensity of the heat received directly from the sun.

Expansion of Water by Heat.—It has been seen that the general effect of a rise of temperature upon bodies is to cause them to expand, and that a fall in temperature causes a contraction. Water forms an interesting exception to this rule, which it will be desirable to describe in detail.

§ EXPT. 68.—Partly fill a thermometer tube and bulb with distilled water, and surround it with snow or melting ice, or a freezing mixture, using an arrangement like that in Fig. 39. Arrange the thermometer tube so that the level of the water can be seen. Notice that the water steadily falls until a certain temperature is reached, when it begins to expand again, soon after freezes, and suddenly expands very much and perhaps breaks the thermometer.

It has been already pointed out that contraction must be accompanied by increase of density, hence the gradual contraction noticed in Expt. 68 indicates a gradual increase of density, and consequently when the contraction ceases the density has reached its highest value and the temperature at which such contraction ceases is referred to as that of *maximum density*.

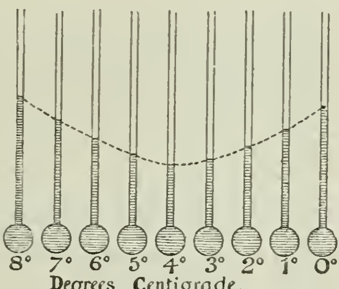

FIG. 39.—Behaviour of Water when cooled from 8° C. to 0° C. On becoming ice, a sudden expansion occurs, but this is not shown in the diagram.

The diagram (Fig. 39) will make the matter clearer, the series of thermometers are to represent the tube in Expt. 68 at the successive degrees near the point of maximum density. The dotted line joins the levels of the liquid at the different

degrees and forms a "curve of expansion," which is seen to gradually descend to the point of maximum density; then to rise more suddenly until the freezing point is reached, when it solidifies, the ice occupying a much greater volume than the water, and hence is lighter and floats on the top.

Distinction between Heat and Temperature.—The analogy between temperature and water-level has already been referred to, but by considering the simile more fully, much can be learnt about the distinction to which the heading refers. Imagine a cylinder of water; the most accurate determination of the height at which the water stands gives no information concerning the quantity of the liquid contained by the cylinder; similarly, a complete knowledge of the temperature of a body tells nothing about the quantity of heat which can be got out of it. Just as the water-level and temperature are comparable terms, so the quantity of water in a vessel can be compared with the quantity of heat in a body. To ascertain the quantity of water in the cylinder, in addition to knowing the height of it, the capacity of the cylinder for water or its size must be known: so also to measure the heat of the body, in addition to knowing its temperature, we must also be informed of its capacity for heat.

EXPT. 69.—Arrange three glass cylinders, of different diameters but equal heights, in a row. Pour a wine-glassful of water into each of them in succession. Notice that the same quantity of water fills the cylinders to different extents. The level is highest in the cylinder of smallest diameter and lowest in the one of largest diameter. The capacity for water of the one with the greatest diameter is evidently more than in either of the other cases, and consequently the same quantity of water fills them to extents inversely proportional to their capacities for water.

§ EXPT. 70.—Heat equal weights of lead and water in the same beaker. Provide two other beakers containing equal weights of cold water. Put the hot lead in one of these, the hot water into the other. Stir and note the temperatures.

§ EXPT. 71.—Take balls of different metals of, say, lead, iron, tin, bismuth, with hooks attached; also a cake of beeswax about $\frac{1}{4}''$ thick, and arrange it on the ring of a retort stand as in Fig. 40. Suspend the balls from a wire support (as shown) in a bath of oil heated to about $150°$ C. Drop them together on to the cake of wax. Notice the iron ball melts through first, then the tin, followed by the lead, and last of all the bismuth.

Evidently all the balls were at the same temperature when dropped on to the wax. The rate at which they melt through depends chiefly upon the amount of heat they give out to the wax, so that since the iron gets through first it had most heat to give out, or its capacity for heat is greatest of all the metals taken. The experiment teaches therefore that the different metals have different capacities for heat. Though these bodies were at the same temperature, the amounts of heat they took up from the oil differed because of their different capacities for heat.

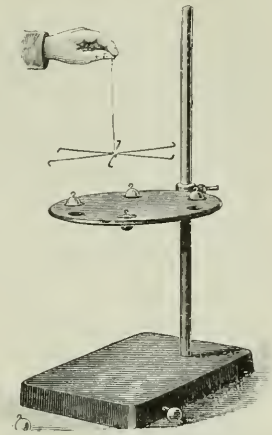

FIG. 40.—To illustrate Experiment 71.

§ EXPT. 72.—Mix 1 lb. of water at the temperature of the air with 1 lb. of iron at 100° and notice the temperature of the mixture. Mix 1 lb. of water at 100° with 1 lb. of iron at the atmospheric temperature and notice that the resulting temperature is in the latter case much the higher.

§ EXPT. 73.—Shake up known weights of water and mercury at different temperatures, and note the resulting temperatures. Repeat, using water and turpentine at known but different temperatures. Confirm by shaking up mercury and turpentine. The relative capacities for heat are inversely as the weights, and inversely as the rate of change of temperature.

Water has the greatest capacity for heat of all forms of matter, and if we institute a comparison between the amount of heat required to raise a certain mass of water through 1°C. and the amount required to do the same thing with an equal mass of another substance, we obtain a ratio or a "specific" relation as we did in comparing the densities of bodies. This ratio is called the *specific heat*, which can be defined as follows :—

The specific heat of a material body is the ratio between the amount of heat required to raise a certain mass of the substance through 1°C. and that required to raise an equal mass of water through the same range of temperature.

Measurement of Quantities of Heat.—As in all other cases of measurement, we must have some unit in terms of which to compute the quantity of heat which is being measured. The *unit of heat* generally adopted *is the quantity of heat necessary to raise the temperature of one gram of water through* 1°*C*. In terms of this unit the amount necessary to raise ten grams of water through 1° would be ten units of heat, or that required to raise one gram through 10° would be the same amount. In estimating the quantity of heat taken up or given out by a body we find the product of three quantities, viz., its mass, its specific heat, and the range of temperature through which it is heated or cooled respectively.

Change of State.—The first effects on heating a solid, as has been seen, are to raise its temperature and to cause an increase in its volume. If we continue the process of heating, the solid state gives place to a liquid condition or the solid melts or fuses. Common experience affords many examples of this, *e.g.*, when a lump of lead is heated its temperature rises and it gets larger, and as the heating is continued it is converted into a silvery liquid. Wax, ice, and iron are other examples. But the temperature at which the liquid state is assumed, *i.e.*, the *melting point*, is widely different in the case of different substances, as the following table shows :—

Examples of Melting Points.

Ice	0°C.	Tin	230°C.
Beeswax . .	65°	Lead. . . .	330°
Sulphur . .	115°	Cast Iron . .	1200°

Latent Heat of Fusion.—It has been already pointed out that when ice is melting the mixture of ice and water remains at the same temperature as long as any ice is left, although the mixture is being continuously heated. The heat which is thus absorbed, and has no effect on the temperature of the mixture, is used up in causing the change of state from solid to liquid, and since it lies hidden, as it were, is referred to as the *latent heat of fusion* or the *latent heat of water*. This quantity of heat can be defined as being *the number of units of heat which are required to change the state of the unit mass*

of ice, converting it from the solid to the liquid condition without raising its temperature.

To melt one pound of ice requires as many heat units as are necessary to raise a pound of water from 0° to 80° C., or as much heat as is wanted to raise 80 lbs. of water through 1° C. In just the same manner, before a pound of water can be changed into a pound of ice we must take away from it just the same amount of heat. Bearing this in mind, it is easy to understand why it takes so many cold nights to cover a pond over with ice, and why it takes such a long time, too, to completely melt the snow in our roads even after the thaw has set in.

Boiling and Vaporisation.—Starting with a lump of ice and gradually heating it, as has been now fully described, the ice is converted into water, and when all the ice has disappeared the temperature of the water gradually rises. The volume at first, however, does not increase with the rise of temperature, for up till 4° C. the volume of the water steadily decreases, but after that point has been passed the temperature and volume increase together.

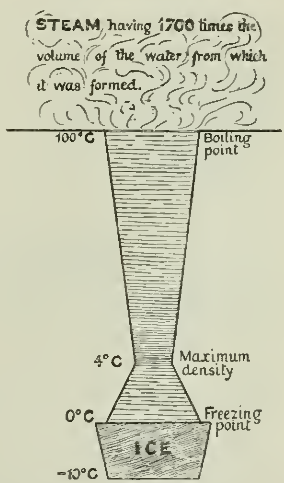

FIG. 41.—Changes of Volume accompanying Changes of State of Water.

The process by which water and other liquids are heated must be noticed here. The water nearest the source of heat gets heated, expands, and in consequence gets lighter; it therefore rises through the general mass of the liquid. Something must take its place, and the cold water at the top being heavier sinks and occupies the space of the water which has risen. This water in its turn gets heated and rises, and more cold water from the surface sinks. This gives rise to upward currents of heated water and downward currents of cool water, until by-and-by

the whole of the water is heated. These currents are known as *convection currents*, and the process of heating in this manner is called *convection.*

§ EXPT. 74.—Heat over a small flame a round-bottomed flask full of water, as in Fig 42. Throw into the water some solid colouring matter, like cochineal, aniline dye, litmus, &c. Notice how the hot and coloured water ascends.

Eventually the general mass of the water gets so hot that the bubbles of vapour which are formed near the source of heat are not condensed again in their upward passage through the liquid, and coming to the surface they escape as steam. The liquid is then said to *boil.* The temperature at which bubbles of this sort get formed throughout the mass of the liquid is quite definite (when the pressure of the atmosphere is the same), and is called the *boiling point.* The student must distinguish between evaporation and boiling. In the former case vapour is produced at all temperatures, but only from the surface, whereas in boiling the vapour is formed throughout the mass at a definite temperature.

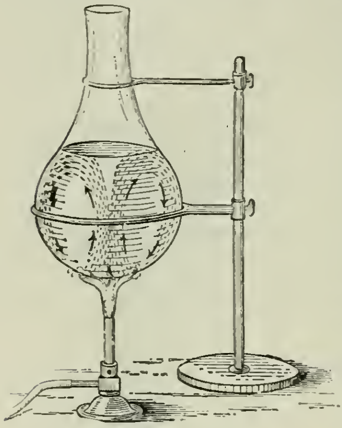

FIG. 42.—Convection Currents.

Effect of Pressure on the Boiling Point.—A word or two must be said with respect to the reservation which has been made about the pressure of the air. It will be seen more fully later that the weight of the atmosphere is very considerable. It presses upon the surfaces of all bodies with a force dependent upon its weight, which, like all other forms of matter, is proportional to its mass, and the mass of the atmosphere will depend upon the extent of the air above the body, which will clearly be less at the top of a mountain or more at the bottom of a mine.

If we wish to boil a liquid, therefore, in those cases where the pressure of the atmosphere is great we shall have to heat the liquid more before the bubbles of vapour can escape at the surface than we shall have to when the pressure is less. If we heat the liquid more its temperature will get higher before there is any conversion into vapour, and consequently its boiling point will be higher when the pressure is greater. In finding the boiling point of a liquid we must therefore know the pressure of the atmosphere at that place and time.

§ EXPT. 75.—Get a well-fitting, sound cork to fit the neck of a 4-oz. round-bottomed flask. Boil water in the flask till all the air is expelled. Remove the burner and cork up the flask as rapidly as possible. Turn the flask over and pour cold water on the top. Notice that as the pressure is diminished by the condensation of the vapour the water boils again at a lower temperature.

Latent Heat of Vaporisation.—As soon as a liquid boils it will be noticed that the thermometer will remain stationary as long as there is any liquid left. After boiling has commenced all the heat is absorbed in changing the substance from the liquid to the gaseous state. This heat also becomes "latent" and is referred to as the *latent heat of vaporisation* or the *latent heat of steam;* it can be defined as '*the number of heat units required to change unit mass of water into unit mass of steam without changing its temperature.*

The latent heat of water can be measured by mixing a known quantity of ice with a known quantity of warm water and ascertaining the amount of heat given up by the warm water to melt the ice. In a similar manner, by mixing a known quantity of steam with a known amount of water and ascertaining how much heat the steam gives to the water, we can measure the latent heat of steam.

§ EXPT. 76.—Put some ice into a known weight of hot water. Notice the temperature when the ice is melted. Determine the weight of the ice by reweighing the water. Notice that a small quantity of ice requires a large quantity of heat to melt it.

§ EXPT. 77.—Pass steam, produced by heating water in a flask, through a delivery tube into cold water. Notice the rapid rise in temperature of the water, and determine the weight of water condensed.

There is an absorption of heat which has no effect on the thermometer whenever a liquid is converted into a vapour. We

have taken the case of water as an example, but the same general phenomena can be noticed in every case.

Expt. 78.—Pour a few drops of any very volatile liquid, such as ether or carbon bisulphide, upon the hand. It soon disappears, and as a result of its disappearance the hand feels very cold. The heat necessary to effect the change of state has been taken from the hand.

§ Expt. 79.—Place a few drops of water between the bottom of a small beaker and a block of wood. Put some ether into the beaker and blow over it with a pair of bellows having a tube fastened to the nozzle. The water will freeze.

When the weather is hot it is a common plan to wrap wet cloths round bottles of wine to keep the beverage cool. In this case the evaporation of the water on the cloth is possible only by the absorption of a large amount of heat, which is extracted from the bottle. For precisely the same reason water is kept in porous vessels in hot countries.

Since it is possible for water vapour to become water only after this large amount of heat has been taken from it, it is clear that the vapour in the air can only be condensed into rain comparatively slowly, and not all at once as would happen if there were no latent heat of vaporisation.

Heat is transmitted by Conduction, Convection, and Radiation.—The transference of heat from place to place will be brought before the student on two or three occasions later, and he will do well to clearly distinguish the ways in which it can be brought about. Heat is conveyed by *conduction* from one particle of a body to the next, the heat travelling from the hotter to the colder parts, and causing no visible movement of the parts of the body. This is the process by which heat passes through solids. Those substances which easily transmit heat in this way are called *good conductors*, while those which offer a considerable amount of resistance to its passage are called *bad* conductors.

§ Expt. 80.—Wrap a piece of paper smoothly round a brass tube and hold in the flame of a gas burner. The paper is not scorched. Wrap the paper around a wooden rod of the same size, and heat as before; the paper is scorched. Brass is a good conductor, wood but a poor one. How does this explain what you have noticed?

§ Expt. 81.—Twist an iron and a copper wire together at one end. At about four inches from the joint fasten a marble on each with beeswax. Heat the joint in a Bunsen flame. Notice that the marble on the copper is the first to fall. Why?

§ EXPT. 82.—Make a short coil of stout copper wire $\frac{1}{8}$ inch internal diameter. Pass it over the wick of a candle without touching the wick. The candle is extinguished, the heat required for it to burn being conducted away by the wire.

§ EXPT. 83.—Turn on, but do not light, a gas jet. Hold over it a wire gauze, and light the gas above the gauze. Notice that the flame does not strike through. This is the principle of the construction of the Davy lamp used by miners.

Liquids and gases are heated by *convection* in the manner which has been before described. In this way of conveying heat there are visible movements of the particles of the body, as has been shown by a previous experiment.

Liquids are bad conductors of heat, but gases are far worse, as the following experiments indicate :—

§ EXPT. 84.—Examine the shadow of a red-hot poker. Notice that the heating of the air as exhibited by its undulation extends but a very little way downwards, thus showing that air is a bad conductor of heat.

§ EXPT. 85.—Place a little lime in the palm of the hand and bring the point of the hot poker upon it. The air enclosed in the lime does not conduct the heat of the poker, so the hand is not burnt.

"Heat is said to be transmitted by *radiation* when it passes from one point to another in straight lines with great speed and without heating the medium through which it passes." This form of heat is referred to generally under the name of radiant heat, but since it does not warm the medium through which it passes it is seen that it is not really heat at all ; it is best studied in the next chapter under the general term radiation. But it can be absorbed and give rise to the sensation of heat, for as everybody knows we warm ourselves "by sitting in the sun," or by standing in front of a fire. The subject will be more fully dealt with in the next chapter.

CHIEF POINTS OF CHAPTER VI.

Discrimination between Heat and Temperature.

Heat.	*Temperature.*
A particular condition of vibration of the particles of a body.	The intensity of the vibration of the particles of a body.
Capable of producing change of temperature.	Is changed by the addition or withdrawal of heat.
Measured in heat-units.	Measured by degrees.
Analogous to water flowing from high to lower levels.	Analogous to difference of level.

Effects of Heat.

Change of Size.	*Change of Temperature.*	*Change of State.*
Substances expand when heated and contract when cooled, the amount of change varying with different materials.	When a body is gaining heat it rises in temperature, and when it is losing heat it falls in temperature.	By the addition of heat a solid can be melted into a liquid, and then vaporised; the changes happen in the reverse order if sufficient heat is withdrawn.

A Thermometer is an instrument for measuring temperature. Its action usually depends upon the fact that substances expand when heated and contract when cooled.

Why Mercury is generally used in Thermometers.—The following are the chief reasons why mercury is the best liquid to use in thermometers under ordinary circumstances:—

(1) It remains liquid through a long range of temperature ($-40°$ C. to $357°$ C.).

(2) It expands considerably for a small rise of temperature.

(3) Its amount of expansion for one degree rise of temperature is fairly uniform while it remains liquid.

(4) It is a good conductor of heat, and therefore it quickly assumes the temperature of objects surrounding or touching it.

(5) Comparatively little heat is required to raise its temperature, that is, it has a low specific heat.

(6) It can be easily seen, and does not wet the glass containing it.

Thermometric Scales.—The distance between the marks of freezing and boiling points on the stem of a thermometer may be divided as follows:—

	Fahrenheit scale.	Centigrade scale.
Boiling point	212°	100°
Freezing point	32°	0°

Changes of Volume of Water.—The changes of volume of water between the boiling and freezing points are as follows:—

Water contracts down to $4°$ C. and then expands to $0°$ C. when it suddenly expands more and freezes into ice. If further cooled the ice contracts.

Water at $0°$ C. contracts up to $4°$ C., and then expands until it boils.

Remember that ice floats on water, and that ten cubic feet of water will make eleven cubic feet of ice.

Capacity for Heat.—Some substances have a greater capacity for heat than others. This is analogous to vessels of different sectional area.

Capacity to hold Liquids.	*Capacity for Heat.*
The same quantity of water poured into a narrow and into a wide jar produces different changes of level.	The same quantity of heat produces different temperatures (heat level) in different substances.
A wide jar contains a greater quantity of water than a narrow one filled to the same height.	A body having a large heat capacity, if at a given temperature, contains a greater quantity of heat than the same weight of a substance of less capacity for heat at the same temperature.

Quantity of Heat.—The amounts of heat absorbed (or given out) by equal weights of different materials when heated (or cooled) through the same range of temperature are in general different.

Change of State.—Many solids change into liquids, and liquids into gases, at definite temperatures. During these changes of state heat is absorbed without rise of temperature. The change of state generally involves a change of volume.

$$\text{Solids} + \begin{matrix}\text{latent}\\ \text{heat of}\\ \text{liquefaction}\end{matrix} = \text{Liquids.} \qquad \text{Liquids} + \begin{matrix}\text{latent}\\ \text{heat of}\\ \text{vaporisation}\end{matrix} = \text{Gases}$$

Transmission of Heat.—Heat travels from one body to another by conduction, convection, or radiation.

Conduction.	*Convection.*	*Radiation.*
The particles pass on the heat vibrations from one to the other. This is how solids get hot.	Hot particles move away from the source of heat, and cooler ones take their place. This is how liquids and gases chiefly get heated.	Due to the vibrations of a heated body being transmitted through the ether: example, the heat of the sun transmitted through space to the earth.

Questions on Chapter VI.

(1) What changes of volume take place when water freezes? State some effects produced (1895).

(2) (*a*) Why is the bulb of a thermometer made with a narrow bore, while the bulb is large?

(*b*) Why is the top of a thermometer sealed up?

(*c*) Why is mercury the best liquid to use in a thermometer under ordinary circumstances?

(*d*) Under what circumstances is alcohol used instead of mercury? (1892).

(3) Describe experiments to prove the expansion by heat of (*a*) a solid, (*b*) a liquid.

(4) How are the "fixed points" of a thermometer determined?

(5) Draw some distinctions between heat and temperature.

(6) Describe an experiment to show that different substances at the same temperature have different quantities of heat.

(7) State the meaning of "conduction" and "convection" as applied to heat.

(8) How would you prove that when ice is melted into water heat is absorbed without rise of temperature?

CHAPTER VII

RADIATION

In Chapter V. the student has had his attention directed to this subject in considering energy. Radiation was there regarded as a form of energy, and was seen to present itself under several different aspects. Sound was instanced as an example of radiation which, resulting in the first place from a sounding body, is transmitted through the surrounding medium, air, as a vibration of its particles. The vibrating source of sound sets the neighbouring air particle oscillating backwards and forwards, and this one, in its turn, sets its neighbour in motion in the same way all along the line of travel of the sound disturbance. But after the passage of the disturbance the air returns to its previous condition and undergoes no change. Such a mode of propagation is spoken of as *wave-motion*.

In this chapter, however, we shall chiefly concern ourselves with those radiations which are conveyed through the other medium which has been referred to, known as *the ether*, which pervades all space, as well as existing throughout the mass of all material bodies. These radiations are also propagated by waves, though in a different manner from that in which sound travels in the air, and may be regarded as *ether-waves*.

Waves.—Before the nature of wave-movements in the ether can be understood it will be necessary to learn what is meant by a wave, as well as those terms which are used in speaking about them, and this cannot be better done than by beginning with waves on water. Everybody has started these by dropping a stone into a still pond. Where the stone is dropped the water is pushed down into a hollow cavity which, as it is watched, spreads in every direction until the edge of the

pond is reached. Had a cork been placed upon the water, it would have been noticed that when the disturbance reached it, all that happens to it is an up and down motion. It does not move forward with the wave. The downward motion of the water producing the depression when the stone comes into contact with the pond is followed by the production of a crest by the swinging back of the water particles, and this crest moves across the pond immediately after the depression and with the same velocity. This is succeeded by the formation of another depression, which is followed by a second crest, and so on until the effect of the stone has died away. The distance from one crest to the next or from one depression to the next is called a *wave-length*.

It must be very carefully noticed that the water particles themselves move *up and down*,[1] or vertically, as shown by the cork, whereas the wave itself moves along the surface of the water, or *horizontally*. These two directions are at right angles to one another, and such a wave is called a **transverse** wave.

EXPT. 86.—Tie a long rope to a peg on the wall. Take the free end in your hand and, holding the rope slack, move your hand sharply from left to right and back again. Notice the wave which travels along the rope. The rope is at right angles to the direction in which the hand moved and consequently, since the motion of the particles of the rope follows the direction in which the hand moves and the wave travels along the rope, this is a transverse wave.

If the motion of the particles is in the same direction as that of the propagation of the wave motion the wave is called **longitudinal**.

Ether-waves are of the first kind, *i.e.*, transverse waves; sound waves in the air are of the latter kind. Fig. 43 is a representation of a transverse wave. The various particles *a*, *b*, *c*, &c., were, previous to the

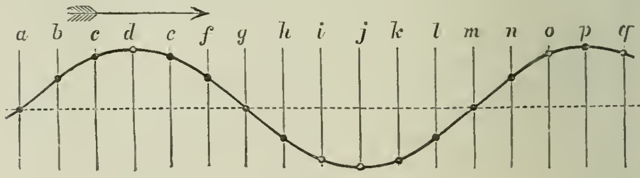

FIG. 43.—A Transverse Wave.

passage of the wave-motion, in a row along the dotted line. The disturbance which gave rise to this wave set the particles in motion, each one moves up and down like a pendulum, and their position at a given instant is shown in the figure. The distance from *a* to *m* is a wave-length, that from *a* to *g* is a half wave-length. The contour of the figure itself, without going into the matter in detail, is sufficient to show us that while *m* is moving in the same direction as *a*, *g* is moving

[1] Really each particle of water moves round in a circle, but the statement in the text brings out the nature of tranverse waves.

in the opposite direction, *i.e.*, since both these particles are moving with the same velocity (for this is another necessary condition), a and m are *in the same phase*, but a and g, though they have the same velocity, are moving in opposite directions and are not in the same phase. Referring to the figure again, it will be seen that if we produce the dotted line and continue the wave line until we have another particle moving in the same direction as a and m are moving, that we shall have another wave-length represented, or, looking at it in another way, the disturbance has travelled for a sufficient time to complete another vibration, so that we can get a second definition of a wave-length, viz., the *distance through which a wave travels in the time necessary to complete a vibration.* The distance a wave travels in a second will depend upon the number of vibrations in a second and the wave-length, and will equal the product of these two quantities, or

Velocity of wave = number of vibrations × wave-length.

Ether-Waves are of Three Kinds.—The ether-waves which come to our planet from the sun, and comprise what is inclusively called sunlight, produce different effects. If they fall upon our bodies they may be absorbed, and the energy of the wave-motion become converted into heat, and for this reason the waves which have been absorbed are spoken of as *Radiant Heat*; if they fall upon the retina of our eye, they may produce a sensation of light, and we call the waves *Light*; falling upon a photographic plate or upon a green leaf, they may produce certain chemical effects, and are then referred to as *Actinic rays*. The word "rays" means simply kinds of radiation, and hence we may speak of heat rays, light rays, and actinic rays. It cannot be too strongly insisted that in their passage through the ether these ether-waves do not give rise to any of these results; they are simply waves transferring energy by wave-motion.

Actinic Rays.—The question naturally arises, How do the waves which give rise to chemical decomposition differ from those which produce the sensation of light, and both these again from those which by their absorption cause a development of heat? The effect of the ether-waves depends very largely upon their frequency, that is to say, upon the number of vibrations in the ether in a given time. Those which move most rapidly, or, what is the same thing, whose wave-length is very short, are most active chemically, and are called *Chemical rays*; they are so rapid that the eye is blind to them. They are consequently sometimes referred to as *Invisible rays*. Since the most rapid waves which are

visible give rise to the sensation of violet, these still more rapid vibrations are also spoken of as *Ultra-Violet rays.*

The most rapid ether-waves are, then, variously called chemical, actinic, invisible, or ultra-violet rays.

Light.—It has just been said that the most rapid visible rays give rise to the sensation which we call violet. What will be the difference in the effect on the retina of slower but still visible rays? It is found that within the limit of visibility each wave-length corresponds to a particular colour sensation. As will be seen later, the violet sensation gives place to indigo, blue, green, yellow, orange and red sensations, in order, as the frequency is regularly diminished. As the waves get slower and slower it follows that they become longer and longer. The slowest and longest visible waves are thus those which produce a sensation of red on the retina.

Radiant Heat.—When the limit of visibility is passed we can still become aware of the existence in the ether of still slower and longer waves than those we have spoken of, and that is by their heating effect. These waves are referred to as *dark heat-waves.* But at the same time all ether-waves can produce heat, for their energy is all converted into heat when they fall upon and are absorbed by substances like lamp-black. In the same manner under proper conditions, light-rays and dark heat-rays may produce chemical effects. All these facts may be summarised by saying the slowest waves may produce heat, and, under exceptional circumstances, certain chemical decompositions; waves of medium rapidity may produce heat, the sensation of light or chemical effect; the more rapid ones may produce heat or chemical effect according to the substance upon which they fall.

Radiation Travels in Straight Lines.—It will be sufficient to demonstrate this in the case of those ether-waves which are of that frequency which enables them to give rise to the sensation of light, and we can do this by examining the path of these waves as they pass through the hole in a shutter of a darkened room. Though, as has been learnt, the light-waves are not themselves visible, yet the path of the light becomes apparent because the minute particles of dust in the air are rendered luminous by the vibrations of the ether being absorbed by them. The path of the light can thus be followed, and is seen to be in a straight line. We can infer this from several every-

day experiences. We cannot see round a corner; if light travelled in lines that sometimes formed bends (we are speaking of a uniform medium), there is no reason why we should not. Or, again, every one knows that it is only necessary to put a small obstacle in the path of the light from a luminous body to completely shut out our view of it. The light from the setting sun, when the sky is cloudy, is often seen to travel in straight lines.

EXPT. 87.—Take three cards and make a small hole in each with a fine needle. Fix the cards on to wooden blocks so that all the holes are at the same height and in a straight line. Place a lighted candle in front of the card, and look through the third. As long as the holes are in a straight line you can see the light from the candle shining through. Move one of the cards aside, and notice that you can no longer see the light. It must be remembered that what we have said about light applies equally to all other kinds of radiation. (From Jones' *Heat, Light, and Sound*).

§ EXPT. 88.—Place a stick vertically between the wall and a long thin luminous gas flame. Notice that the shadow of the stick is sharply defined.

§ EXPT. 89.—Construct a pin-hole camera as follows:—Make two paste-board tubes, by rolling pasted paper on a wooden cylinder, so that one fits inside the other. For the wider tube previously cover the cylinder with dry paper. Cover one end of the narrower tube with tissue paper and thrust this end into the wider tube. Line with black paper. Notice pictures on the tissue paper. Reason out how they are formed.

§ EXPT. 90.—Cover a lantern cap with tinfoil, remove the condensing lens, and place the cap on. Make pin-holes in the cap. For every pin-hole there is an image formed on the screen. Make the pin-holes more and more numerous, and near together, till the images overlap and become confused. At last diffused light is produced, which is an overlapping of images.

Reflection of Radiation.—When a wave is said to be *reflected*, it is understood that it comes into contact with the surface of some body, and is thrown back from that surface, and travels in a direction opposed to that in which it was originally moving. This may happen in two ways, either *regularly* or *irregularly*. In the first case it is turned back according to fixed rules, while in the second there is no uniformity about the reflection. The page on which this is printed appears to be white because of the irregular reflection of the light which falls upon it. Or, if we powder a sheet of glass, the powder seems to be white for a similar reason; there are many surfaces formed from which irregular reflection takes place.

Regular Reflection.—It will be most convenient to study the rules of the reflection of ether-waves by taking light-rays as an example. Light is regularly reflected from plane mirrors, which can be made from a variety of substances, the most common being bright metal or silvered glass.

EXPT. 91.—Cut out a semicircle of cardboard, and divide it as shown in Fig. 44. Fix it in an upright position on a block of wood by glueing little pieces of wood on to the block on both sides of the card as shown. Place a piece of looking-glass horizontally at the centre of the card on the wooden block. Thread a silvered bead on to a pin, and stick the pin into the edge of the card. Blacken a glass tube of half an inch diameter, and look at the mirror through it, the tube forming a radius of the circle of which the card is a half. Notice that when the

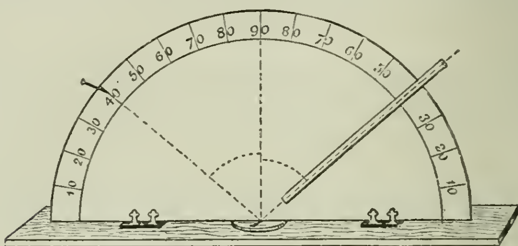

FIG. 44.—Reflection of Light.

bead can be seen, the tube crosses the division on the opposite quadrant with the same number against it as that at which the bead is attached. Vary the position of the bead, and observe that the tube must be similarly altered. Place the bead at 90, and see that the tube must be placed there also.

The same facts can be demonstrated in another way :—

§ EXPT. 92.—Fasten a little whitened wooden stick with wax perpendicularly at the centre of a plane looking-glass. Cast upon the mirror at the foot of the rod a beam of parallel rays from the lantern or a sunbeam coming through a hole in a screen. Notice (*a*) that the reflected beam always makes the same angles with the mirror and the stick as the incident beam does, and (*b*) that the incident beam, the stick, and the reflected beam all lie in one plane.

From these observations we learn that the light strikes the mirror at a certain angle and leaves it at the same angle. The angle at which the light or any sort of wave strikes the reflecting surface is called the *angle of incidence*, and the wave an *incident*

wave. The angle at which the wave leaves this surface is known as the *angle of reflection*, and the wave as it leaves the *reflected wave.*

Thus, in Fig. 45 I N represents the incident wave and N R the reflected wave. The angle I N P is the angle of incidence, the angle P N R the angle of reflection. Referring again to Expt. 91, it must be noticed that it is only when the three lines, viz.—(1) the line joining the bead to the mirror, or, as it has been called, the incident wave; (2) the tube, which represents the reflected wave; (3) and the *normal*, that is the line at right angles to the mirror from the point where the incident ray touches it—are all in the same plane, that the bead can be seen. Hence we get the following laws of reflection :—

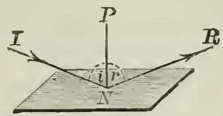

FIG. 45.—The Angle of Incidence and the Angle of Reflection.

1. *The line representing the reflected wave is in the same plane with the normal and the line representing the incident wave, and is on the opposite side of the normal from the incident line.*

2. *The angle of incidence is equal to the angle of reflection.*

The student must carefully bear in mind that these laws apply equally to all forms of radiation, whether in the ether or in air, *i.e.*, to all ether-waves and to sound.

It was also learnt from Expt. 91 that when a wave strikes a reflecting surface *normally*, *i.e.*, having travelled along the normal, it is reflected back along the same line.

When a Mirror rotates, the Angle through which the Image moves is twice the Angle through which the Mirror moves.

EXPT. 93.—At one end of a piece of board 1 foot long, by 4 inches wide, fasten by sealing-wax a cork upright, through this pass horizontally a piece of glass tube about 2 inches long and $\frac{1}{4}$ inch internal diameter. Stretch a vertical thread across the opening of the tube nearest the other end of the board. Towards the other end of the same side fasten a circular sheet of cardboard divided into degrees, the 0° being nearest to the tube and in the middle of the board. Pivot in the centre of the circle two radial arms, one above the other, one carrying at its end a vertical pin, the other a central mark. The second carries a 2 inch square piece of silvered glass in a vertical plane perpendicular to the arm. The pin bearing arm being placed anywhere, the mirror bearing arm is turned till the reflection of the pin is seen and coincides with the thread in the tube. Whenever this is the case, the reading of degrees

indicated by the pin is always twice as great as where the marked arm is.

This fact has to be borne in mind in using the Sextant, an instrument which is used to measure the angle subtended by two distant objects.

Refraction of Radiation.—Up to the present the ether-waves have been supposed to be moving through a medium of a uniform density throughout. When this is the case, as we have seen, the radiation travels in straight lines, and, coming into contact with a reflecting medium, is turned back, according to the laws which have been studied. If, however, the radiation passes from one medium into another of a different density the

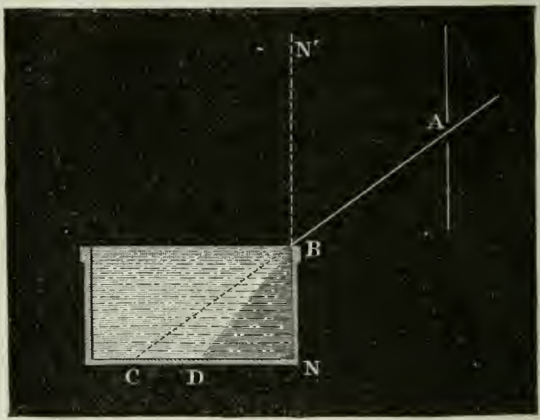

FIG. 46.—Refraction of Light.

propagation of the wave is no longer rectilinear, the passage from one medium into the other is accompanied by a bending of its path. This bending is known as *refraction*, and the ray is said to be *refracted*. It will be simplest to describe how this can be shown experimentally in the case of light-waves, but what holds good of waves of this particular length holds true of all ether-waves, as well as of any other kind of radiation.

EXPT. 94.—Take a rectangular metal box, such as a cigarette box, and put a wooden or metal scale on the bottom. In a darkened room let sunlight fall slantwise against the edge. The side of the box throws a shadow which reaches, say, to C (*see* Fig. 46), which, since light travels

in straight lines in the same medium, is a continuation of the rays of sunlight A B. Without disturbing anything fill the box with water. The shadow no longer reaches to C, but only as far as D. Clearly the light-waves have been bent or refracted out of their original course. Notice that N N′ is the normal, and that the light travelling from the comparatively rare air into the comparatively dense water is refracted towards the normal. (From Jones' *Light, Heat and Sound.*)

§ EXPT. 95.—Place a bright object, say a coin, on the bottom of an empty basin, and arrange your eye so that the object is *just* hidden by the edge of the basin. Get somebody to pour water into the basin. You will now be able to see the coin without any movement of your eye having taken place. Evidently there has been some bending of the direction of the light rays somewhere.

In Fig. 47 let C be the position of the coin in which it is just hidden, so far as the eye is concerned, by the edge of the empty

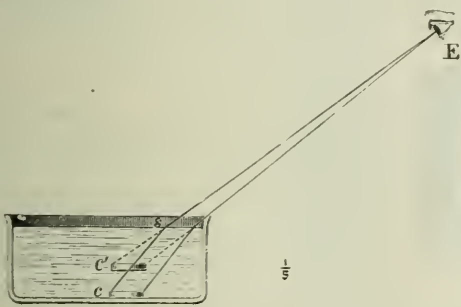

FIG. 47.—Coin Experiment to show Refraction.

basin. If the rays from the coin C be continued in straight lines these lines will evidently pass above the eye. Now when the water is put in, these rays, which before miss the eye, are refracted in passing out of the water and just enter the eye, making the coin appear to be in the position C′. The right side of the vessel, if continued upwards, represents the normal, and evidently in passing out of water into air the light-waves are bent away from the normal.

The following experiments illustrate further the phenomena and rules of refraction :—

§ EXPT. 96.—Stretch a wire across the opening in the cap of a lantern. Focus shadow of the wire on a screen. Interpose a strip of glass in front of the wire and tilt the strip. Notice displacement of part of shadow.

§ EXPT. 97.—Place a glass cell before the lantern and focus it on the screen. Let the surface of the water be visible. Put a lump of ice on the water, and observe the streaky appearance of the illuminated part of the screen. Add syrup, alcohol, and hot water by a pipette.

Pour the vapour of ether out of a bottle, and observe the appearance on the screen. Examine shadow of burning gas, or red-hot poker, and of platinum wire through which a current of electricity is passing.

It is the refraction of light in its passage from one medium into another of different density which explains several very familiar observations. A stick held in anything other than a perpendicular position in water appears to be bent upwards. Standing bodies of water always appear shallower than they really are.

Refraction through a Prism.—Prisms are usually made of glass, though they can be made of other materials. They are in the shape of a wedge, and have plane faces, as shown in Fig. 48.

FIG. 48.—A Prism.

§ EXPT. 98.—Focus on the screen a small circular hole in the cap of the lantern. Introduce a wedge of glass, and show that the spot is moved towards the base of the wedge. Let the first face of the wedge be oblique to the beam. Put a second wedge with the first, face to face and base to base, so as to form a single wedge of double the angle. Notice the double displacement of the light spot. Put them edge to base, notice the emergent beam is parallel to the incident.

The amount of deviation of the beam thus depends upon the angle of the wedge or prism ; it also depends upon the material of which the prism is made and the nature of the incident light.

Refraction through a Lens.—Most lenses are of glass, with curved surfaces, which are portions of spheres. In some lenses one surface is quite plane. All lenses can be divided into two classes—*convex* or *converging*, and *concave* or *diverging*. Converging lenses can be told at once by their power of forming an image of a distant object like the sun, or by that of magnifying. Concave lenses form no image in this way, and, moreover, instead of magnifying, they make objects appear smaller when viewed through them.

To understand their action upon the course of rays of light through them it is simplest to regard them as being built up of parts of prisms in contact, as shown in Fig. 49, where a convex lens is built up in this way. A ray of light falling upon any one of these prisms is refracted towards its thicker part, and consequently they all converge towards a point, which, if the incident rays are parallel, is known as the *principal focus* of the lens, as F in Fig. 50. To actually find the distance of the principal focus away from the centre of the lens, that is, its *focal length*, it is only necessary to form an image of the sun by it on a screen and to measure the distance between the lens and the screen.

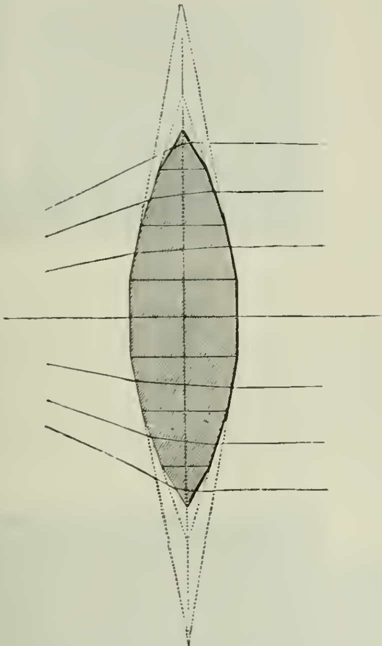

FIG. 49.—Lens built up of parts of Prisms.

The Telescope.—The principle of the refracting astronomical telescope can now be described. Let O, Fig. 51, be a double convex lens forming an image *a b* of the object A B. This image becomes the object to a second smaller, though in other respects similar, lens, placed near the eye. The second lens forms an enlarged image A′ B′ of this first image *a b*, in the way shown in the figure. A lens placed in the same relation to the smaller one as O is in the figure is called the *object glass*, while the smaller one which magnifies the image formed by the first constitutes the *eye-piece*.

Other Forms of Radiation can be similarly Refracted.—The various circumstances which accompany the

refraction of light-waves have been found to apply equally to the longer, slower ether-waves which we have called dark heat-waves. If we make a prism or lens of some substance which

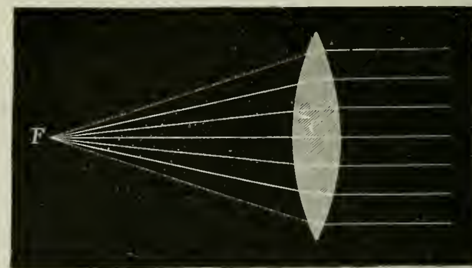

FIG. 50.—To show Principal Focus of a Double Convex Lens.

allows these slower waves to pass through it as easily as glass transmits light-waves, we can obtain similar results by experimenting with them. Such a substance is rock-salt. It has been found by using a delicate instrument known as a thermopile,[1] which reveals the presence of dark heat-waves very readily, in conjunction with a rock-salt prism, that the longer ether-waves

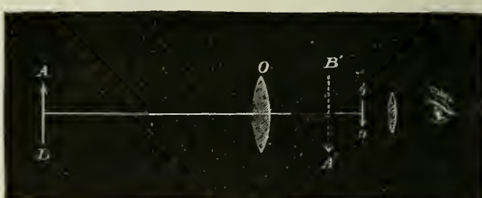

FIG. 51.—Formation of Image by Telescope.

are refracted in a manner quite identical with light-waves. So, too, by using a lens of the same material, these heat rays can be brought to a focus.

[1] For a description of the Thermopile the student must refer to some book on Electricity.

Sound-waves are also refracted under suitable conditions. By filling a balloon with carbon dioxide we obtain a lens which is able to bring sound-waves in air to a focus beyond the balloon, or if instead we use a balloon filled with hydrogen, the sound-waves, instead of being made to converge, are caused to diverge. Thus the balloon of carbon dioxide corresponds to a double convex lens, whereas that filled with hydrogen acts as a double concave lens.

Refraction is accompanied by Dispersion.—In all the cases of refraction which have been considered the phenomena have been described as if all the ether-waves, which are contained in white sunlight, are bent equally, but this is really not so. If the experiments are performed as described, in every case it will be noticed that the image formed by the refracted ray is coloured round its edges. To prevent this complication, and to make the descriptions quite correct, we must suppose that waves of a given length are used, or, as it is called, *monochromatic light*, such, for example, as could be obtained by burning methylated spirit in which common salt is dissolved.

The shortest, most rapid waves are bent most; the slowest, longest waves are bent least. This can be very prettily seen by performing an experiment which was first done by Newton; improving on his method, however, by using a slit through which to let the light pass instead of a round hole.

The Analysis of Light by a Prism. § EXPT. 99.—Allow sunlight to fall through a slit *s*, Fig. 52, into a darkened room. Just inside the room arrange a prism as shown. The component wave-lengths of the white light will be differently refracted by the prism, the rapid vibrations of the ether which give rise to the sensation of violet will be most bent, the slowest vibrations or the red waves will be bent least, and a band of colour continuous between these limits comprised of the colours of the rainbow will be formed.

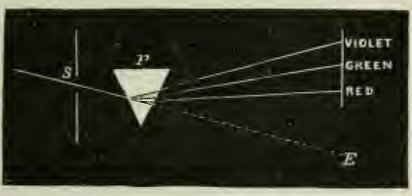

FIG. 52.—The Analysis of Light by a Prism.

In this experiment the light is said to be *dispersed* owing to the different refrangibility of the various kinds of light. An

examination of the band of colour or *spectrum* will show that one colour shades imperceptibly into the next. There is, then, an infinite number of waves of different lengths comprised in the white light from the sun, each wave is bent to an extent depending on its length.

If the decomposed sunlight, instead of being collected on a screen, be passed through a second prism similarly arranged, it will be seen that the band is longer or the dispersion is greater. The amount of dispersion also depends upon the material of which the prism is made. Glass produces a much greater amount of dispersion than water ; flint-glass twice the dispersive power of crown glass ; carbon bisulphide, again, has more dispersive power even than flint-glass.

Recomposition of White Light.—If in Expt. 99, after having decomposed sunlight to form a spectrum, we place a

FIG. 53.—Recomposition of Light by a Second Prism.

second similar prism after the first *with its refracting angle reversed*, it will be seen that the spectrum disappears, and in its place we get a white image of the slit, not opposite the slit but displaced owing to the refraction produced by the prisms. But the refraction is unaccompanied by dispersion. The second prism undoes the dispersive work of the first (*see* Fig. 53).

Or if, after the first prism, a double convex lens were arranged so that the decomposed light falls upon it, it will be found that the dispersed light is recombined and a white image is formed at the principal focus of the lens.

The Colour Disc.—This is an arrangement of Newton's for demonstrating that white light can be made by combining the various colours of the spectrum.

§ EXPT. 100.—Upon a round piece of card paint sectors of the different colours contained in the spectrum, arranging the areas of the coloured

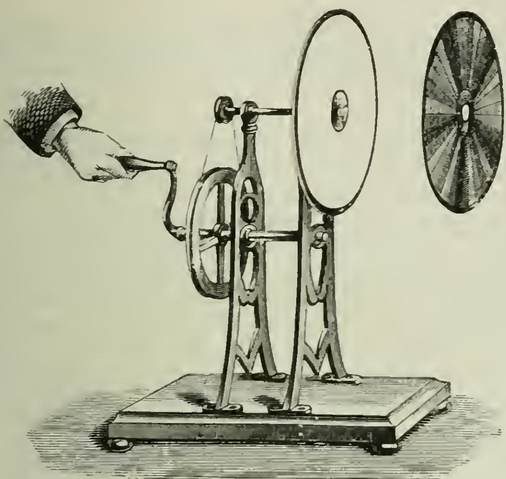

FIG. 54.—The Colour Disc.

sectors as nearly as possible in the proportion in which they occur in the spectrum.

Place the card upon a whirling table (Fig. 54), and rotate it rapidly, when it will be found that light on the card gives rise to the sensation of white or gray.

Colour.—

§ EXPT. 101.—Make an Oxford blue liquid by adding ammonia solution to copper sulphate dissolved in water until the precipitate formed is re-dissolved. Place the blue liquid thus made in a glass cell. Focus the round hole of a lantern cap on the screen. Interpose the filled cell. Notice the pure blue colour. Now interpose red glass either before or behind the cell. Notice that no light can pass now.

§ EXPT. 102.—Paint sheets of cardboard with various brilliant colours. Send the light from a lantern in an otherwise dark room upon them and

catch the reflected light on white sheets of cardboard. Notice that the colour of the light reflected is the same as that of the card from which it is reflected.

§ EXPT. 103.—Use the bisulphide prism to produce a long spectrum of a slit on the lantern cap. Pass the filled glass cell from Expt. 101 through the spectrum and notice that it is only able to transmit blue light. Repeat the experiment with as many coloured transparent solutions as possible.

§ EXPT. 104.—Pass through the same spectrum various coloured opaque bodies, *e.g.*, a rod of sealing wax. Notice in this case it is only coloured when passing through the red rays. It appears a dull grey colour in most parts of the spectrum.

It will be quite clear after performing experiments like those above that the colour of bodies is a property depending upon the light in which they are viewed. A red substance like sealing-wax is red only when there are red rays falling upon it which it can reflect. The sealing-wax absorbs all the other constituents of white light and hence if it is seen by blue light, since all the light rays of this colour are absorbed, no light is reflected and it appears black. A black substance appears so because it absorbs all the constituents of white light. Similarly with transparent substances, they have differing powers of transmitting light of various colours. White transparent bodies like glass transmit all the colours with equal facility. The blue solution used in Expt. 101 can transmit only blue rays, absorbing the colours from red to green of the spectrum. Hence it was that if a piece of red glass is put in the path of the blue light, since the red glass can only transmit red rays, the blue light was absorbed and no light passed the combination of blue liquid and red glass. *The colour of opaque bodies is due to the constituents of white light which they reflect; while that of transparent substances is due to the constituents which are transmitted by them.* The difference between the total constituents of white light and those absorbed by any substance, gives us its colour.

CHIEF POINTS OF CHAPTER VII.

Radiation is the process of transference of energy by ether-waves. It may be regarded as of three kinds, according to the chief effects produced.

RADIANT ENERGY OR RADIATION.

Radiant Heat, or energy of ether-waves convertible into heat.	Light produced by action of ether-waves upon the retina.	Actinic Rays, or ether-waves which produce certain chemical changes.

Rectilinear Propagation of Radiation.—Light, and all other kinds of radiation travel in straight lines when propagated through any one medium, but often have their direction changed when passing from one medium to another (*see* Refraction).

Reflection of Radiation.—Light, and other forms of radiation, in being reflected from suitable surfaces, obeys the following laws :—

(1) The reflected ray lies in the same plane as the incident ray.

(2) The angle of reflection is equal to the angle of incidence.

Refraction of Light.—A ray of light passing from a less dense to a more dense medium is bent towards the perpendicular to the separating surface and conversely.

Refraction by a Prism.—The deviation of a beam of light from its original direction caused by the action of a prism depends upon (*a*) the angle of the prism, (*b*) the material, (*c*) the thickness traversed, (*d*) the length of the ether-waves.

Analysis of Light by a Prism.—The points to be remembered in connection with this are :—

(1) That if a beam of monochromatic light, that is, light of one colour, traverses a prism, it is bent out of its original direction, but the amount of bending produced by any particular prism depends upon the colour of the beam used, being greatest for violet light and least for red light.

(2) That if light from any source pass through a prism, it is broken up or analysed into its different components, each ray of elementary colour that enters into the composition of the light being bent by a different amount.

(3) That if a beam of white light from a slit pass through a prism, it emerges as a coloured strip, termed a *spectrum*.

A beam of white light,	When it traverses a prism is broken up into	Red Orange Yellow Green	Blue Indigo Violet

White light can, therefore, like a chemical compound, be broken up into simpler elements.

Recomposition of Light—The Colour Disc.—The analysis of white light is noted above ; the synthesis, or recomposition, can be effected—

(1) By making the coloured band or spectrum, produced when light has passed through one prism, traverse a second prism having its refracting angle reversed.

(2) By rotating a disc of cardboard painted in segments of violet, blue, green, yellow, orange, and red.

QUESTIONS ON CHAPTER VII.

(1) Describe shortly the construction of an achromatic, astronomical telescope (1889).

(2) How could you show that light travels in straight lines?

(3) Describe experiments to illustrate the characteristics of transverse and longitudinal waves.

(4) State the laws of the reflection of light.

(5) In what direction is a beam of light deviated when it passes from a less dense to a more dense medium?

(6) Name some common phenomena produced by the refraction of light.

(7) Draw a triangle to represent a section of a prism and show how a beam of light is bent by passing through the prism.

(8) State how light can be experimentally analysed by a prism.

(9) How would you prove that white light is composed of several colours, and how can these colours be combined by experiment to form white light?

CHAPTER VIII

THE CHEMICAL COMPOSITION OF MATTER

Physical and Chemical Changes.—Matter is subject to two kinds of change. Hitherto we have only been concerned with those which influence the properties of matter, leaving its composition unaltered. It has been seen that a body, such as a piece of iron, may gradually increase in temperature, changing from cold iron to hot, and, becoming hotter and hotter, may change in colour passing from a dull gray to red, and from red to almost white, eventually becoming incandescent and emitting light rays. But if left to itself the iron will begin to cool, passing through the same changes in the reverse order until it reassumes precisely the former condition. Or, again, we might take a piece of soft iron, and, having wound silk-covered copper wire round it several times, pass an electric current through the wire. It would be found, on examining the iron, that new properties had been imparted to it, that it was now able to pick up other pieces of iron, or had become magnetised. If the electric current be discontinued, the new power, too, disappears. Such changes as these, where the substance or composition of the body remains unchanged, are known as *physical changes*. On the other hand, if a piece of iron be left exposed to damp air for some hours it becomes covered with a reddish-brown powder, which the most superficial examination will show is a different substance from the iron with which we started. There is a very large number of changes of the same kind as this continually taking place around us. When gunpowder

explodes, we have an abundance of smoke formed and a black residue left behind, and it is easy to see that the smoke and deposit are quite unlike the gunpowder before the flash. Such changes as these are called *chemical changes.* It is with changes of this second kind that Chemistry is concerned, and we may define this science thus: *Chemistry is that branch of knowledge which deals with chemical changes; those, namely, which result in the formation of new substances with new properties.*

Chemical Elements.—The result of a large number of experiments made from time to time by different chemists has been to show that there are upwards of seventy different forms of matter which can by no known methods be broken up into anything simpler. By this is meant that if any one of these, such as iron or silver, be selected and treated in any way with which chemists are familiar—for example, if it were subjected to a very high temperature—we should find it impossible to get anything having properties different from what we know to be those of iron or silver, as the case may be. Bodies of this simple kind are called *elements.*

But it must be carefully borne in mind that, as the methods which chemists adopt become more and more refined, it is quite likely that some of these may be found to be wrongly regarded as elements. Up to the time of Davy (1807) the substances soda, potash, and lime were regarded as elements. He found, however, that they could be split up into simpler constituents. From soda he obtained a soft metal, sodium, and two gases, oxygen and hydrogen, and from that time, of course, soda could not be regarded as an element. Similarly, if at any future time it should be found that any of the forms of matter which we call elements can be split up into simpler bodies with different properties, the element which is thus decomposed will have to be struck off the list. Of all the elements known to chemists, only six exist in the gaseous state, under ordinary conditions of temperature and pressure. These are chlorine, fluorine, hydrogen, nitrogen, oxygen, and argon. Two of them, bromine and mercury, are liquids. The rest are solids, and some of the commonest are given in the table.

SOME OF THE COMMONEST ELEMENTS

Gases	*Solids*	
Chlorine	ALUMINIUM	LEAD
Fluorine	ANTIMONY	MAGNESIUM
Hydrogen	Arsenic	MERCURY
Nitrogen	BARIUM	Phosphorus
Oxygen	BISMUTH	POTASSIUM
Argon	CALCIUM	Silicon
	Carbon	SILVER
Liquids	COPPER	SODIUM
Bromine	GOLD	Sulphur
Mercury	Iodine	TIN
	IRON	ZINC

Metals and Non-Metals.—A good many of the elements are possessed of certain distinctive characters in which they resemble one another. They have a bright lustre, a high specific gravity (*see* p. 22), are good conductors of heat and electricity, and are known to chemists as *metals.* There is no difficulty in deciding in a large number of instances that the element possesses the characters of a metal, and the student will immediately think of gold, silver, copper, iron, &c. Other elements, however, are quite as plainly not of this class ; they have no lustre, they are not heavy, nor do they conduct heat and electricity well. These are spoken of as *non-metals*, and phosphorus, sulphur, and carbon will serve as good instances. But the line between the two classes is not a hard and fast one, for one or two of the elements possess some of the properties which distinguish a metal, and yet for other reasons, which the student will understand better later, are not classed with the metals, but with the non-metals. Arsenic may be cited as an instance of an element which possesses properties common to both classes. In the list of elements given in the preceding paragraph the metals are printed in capitals.

Mixtures and Compounds.—The differences between a mixture and a compound will be most easily understood by carefully performing the following experiment.

§ Expt. 105.—Procure some flowers of sulphur or powdered roll-sulphur and some copper powder,[1] in the proportion of four parts by weight of copper to one of sulphur, and shake them together. The result is a mixture of sulphur and copper, the colour of which will be between the yellow of sulphur and the red of copper. If the mixture be examined with a magnifying glass, there will be no difficulty in recognising the particles of sulphur and copper lying side by side. Place a little of the mixture in a test-tube, and pour some carbon bisulphide upon it, and shake well. By this means all the sulphur is dissolved and the copper is left behind. Now heat another portion of the mixture in a dry tube, and carefully notice what happens. First the sulphur melts, and, as the copper gets hot, it suddenly becomes very bright. Allow the tube to cool, and break it to examine the contents. It is neither yellow, the colour of sulphur, nor red, the colour of copper, but almost black. An examination with the magnifying glass reveals no particles of sulphur and no copper filings. No part of the mass will dissolve in carbon bisulphide.

What is this great change which has resulted from heating the two elements together? Clearly, that it has resulted in the formation of a new substance with properties of its own. Such a change as this is known as a *chemical change*, and is said to be the result of *chemical action*. The new substance formed from the copper and the sulphur is called a *chemical compound*, and in this particular case there are two elements held together by a force which is known as *chemical attraction*. We are now in a position to enumerate the peculiarities and distinguishing characteristics of mixtures and compounds.

Mixture.—*In a mixture the components exist side by side, and can be separated by suitable mechanical methods. The components are not held together by chemical attraction, that is, they are not chemically combined. The ingredients can be present in any proportion, and the properties of the mixture are intermediate between those of the constituents.*

Compound.—*A chemical compound is a substance which can be split up into two or more elements. Its constituents are held together by chemical attraction, and cannot be separated by any ordinary mechanical means. It always contains definite weights of the elements composing it, and its properties differ entirely from those of its constituents.*

Familiar Examples of Mixtures and Compounds.—It will not be difficult to find many examples of mixtures

[1] The copper powder is easily prepared by digesting granulated zinc in a solution of copper sulphate.

which are familiar to every one. Gunpowder, for instance, is a mixture of three things—nitre, brimstone, and charcoal. They are, however, so thoroughly mixed that there is more difficulty in separating the ingredients than was experienced in the last experiment.

§ EXPT. 106.—Procure enough gunpowder to cover a crown; put it in a small flask and well cover it with water. Heat the flask gently for some minutes over wire gauze placed above a burner, and then filter what remains in it. Collect the filtered liquid in an evaporating basin and evaporate it to dryness, when a white substance will be left, which is nitre. Scrape the black residue off the filter-paper and shake it up with carbon bisulphide. Filter this solution through a new paper and again collect the liquid in a basin. Leave the basin exposed for a little time to the air and the liquid, which is very volatile, will disappear, leaving the brimstone behind in the form of beautiful crystals. The charcoal which is left on the paper should be dried and a part of it burnt to show its real nature.

This shows us that the constituents of the gunpowder are not held together chemically but exist side by side. In a similar way, the student will have no difficulty in understanding that the amounts of the nitre and other things can to some extent be varied, and that in the other particulars the gunpowder fulfils the conditions of the definition of a mixture. Another familiar mixture is found in the air we breathe. This is made up of nitrogen and oxygen mixed in the proportions of four pints of the former to one of the latter. The reasons for considering the air to be a mixture will be better understood a little later.

From these examples it will be seen that mixtures can be made up of either elements or compounds.

We must now glance at a few common chemical compounds. The simplest of them contain two elements only, and are called *binary compounds*, such as water, lime, common salt. Many others contain more than two elements, and chalk and clay can be mentioned as instances. As we proceed the student will become familiar with many other instances of chemical compounds of varying degrees of complexity, from the binary compound to those containing a large number of elements.

Relative Abundance of the Elements.—All the elements known to chemists are by no means equally abundant; comparatively few of them occur in anything like large quantities. The following table gives some of the most abundant,

and also the amount in 100 parts of an average portion of the earth's crust :—

MOST ABUNDANT ELEMENTS IN THE EARTH'S CRUST.

Oxygen	about	48
Silicon	,,	29
Aluminium	,,	8
Iron	,,	6
Calcium	,,	3
Sodium	,,	2
Potassium	,,	2
Magnesium	,,	$1\frac{1}{2}$

From the table it will be seen that oxygen makes up nearly one-half and silicon about three-tenths of the whole. Of the fraction left to make up the whole, hydrogen is the chief constituent, while scarcely anything is left to account for after the elements carbon, sulphur, chlorine, and nitrogen have been allowed for. Many of the elements remaining are very rare indeed, some of them having been seen only by the favoured few.

Preparation and Properties of a few typical Elements.—It is now desirable to learn something more in detail about a few of the elements, from which, as has been said, the materials which build up the earth and its inhabitants are formed. Oxygen constitutes about one-half of the solid part of the earth, eight-ninths of water by weight and one-fifth of the air by volume. Since we shall have studied the chemistry of so very large a proportion of matter when we have become acquainted with oxygen, we shall begin this section with it.

Preparation of Oxygen from Mercuric Oxide.—Oxygen is easily prepared and examined. When a specimen of the gas is required some compound which contains it is heated.

EXPT. 107.—Into a hard glass tube, which can be made by closing the end of a piece of combustion tubing, put enough red oxide of mercury to fill half an inch of the tube. Loosely close the end of the tube with a cork, and heat it and its contents in a laboratory burner. The substance darkens, and it is soon noticed that the cold upper part of the tube has become covered with a layer of quicksilver or mercury.

When this has gone on for a minute or two, take out the cork and insert into the tube a freshly extinguished splinter of wood which is still glowing. It is re-kindled and bursts into flame. The tube has become full of the gas known as oxygen, and it has come from the red oxide of mercury.

We can represent and best remember what has been done by writing our experiment thus—

RED OXIDE OF MERCURY	gives when heated	MERCURY and OXYGEN.

Preparation of Oxygen from Potassium Chlorate.—When larger quantities, such as bottles full of oxygen, are required, we set to work in a different way. A commoner and less expensive substance, which contains oxygen, is procured, and the one generally chosen is chlorate of potash. This white crystalline compound is made up of three elements—potassium, chlorine, and oxygen—and if heated in the same way as the red oxide of mercury it melts and gives off bubbles of oxygen, and after all the oxygen has been given off a white substance like table salt is left behind. But, by adopting a slightly different method, oxygen can be obtained more readily and easily, for it has been found, that by mixing the potassium chlorate with certain other substances, of which one is a black compound, manganese dioxide, the oxygen from the chlorate comes off more easily and at a lower temperature.

EXPT. 108.—Weigh out twenty-five grams of crystallised potassium chlorate; powder the crystals, and dry the powder in a porcelain dish on a sand-bath. Weigh out five grams of manganese dioxide, and dry in another dish in the same way. After a few minutes take the dishes off the sand-bath, and as soon as the contents are cool mix them together in a mortar. Transfer the mixture to an eight-ounce flask, A, which has been fitted with an india-rubber stopper with a hole through it, through which a tightly-fitting bent glass tube, B, has been passed, as in Fig. 55. Support the flask on a retort stand, or a piece of wire gauze, in such a manner that the end of the bent delivery tube dips under the water of a pneumatic trough, C, as is also shown in the illustration. Lastly, having filled a suitable bottle or jar, D, with water, invert it in the pneumatic trough, allowing no air to get into the bottle during the process. Place the neck of the bottle over the end of the delivery tube to collect the oxygen, which will begin to come off a minute or two after starting to heat the flask when the air in the flask has been driven out. The heating should proceed cautiously and gradually. When the bottle is full, its mouth should be covered with a ground glass plate while it is still

under water. Holding the plate in this position, lift the bottle out of the water and place it on the table, and proceed to fill a second in the same manner.

Oxygen can be obtained in a great many other ways; for example, it is subtracted in large quantities from the air around us, but it is unnecessary here to describe any other methods, as

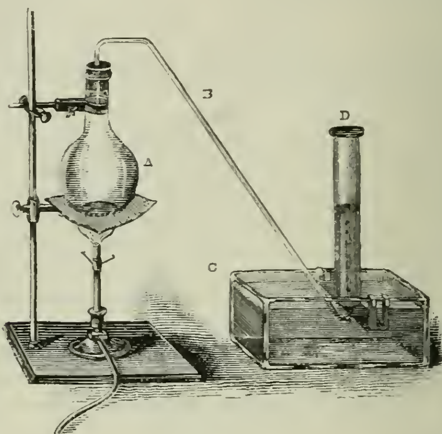

FIG. 55.—Preparation of Oxygen.

we are more concerned in becoming acquainted with the properties of this element. Before leaving the preparation of oxygen, however, we must be quite clear as to what has been done. By heating the potassium chlorate we have broken it up into two things, the gas collected in bottles and the white substance, like common salt and which is called potassium chloride, left behind and containing no oxygen.

POTASSIUM CHLORATE	gives when heated	POTASSIUM CHLORIDE	and OXYGEN.

Properties of Oxygen.—Oxygen is a gas which has no colour, no smell, no taste. It has no action upon litmus-paper.

EXPT. 109.—Take one of the bottles of oxygen (one of those collected last should be chosen). Notice everything you can about the contents of the bottle. It is a *gas* with *no colour*. Remove the plate from the mouth and test its smell; it has *no smell*. Try the taste by breathing some of the gas; it has *no taste*. See if the gas has any effect on moistened litmus-papers, one blue and the other red. There should be no effect; we say oxygen is a *neutral* substance.

Ordinary Combustible Substances burn more brightly in Oxygen.—

§ EXPT. 110.—Attach a piece of stout wire to a wax taper as shown in Fig. 56, and having lighted the taper plunge it into another of the

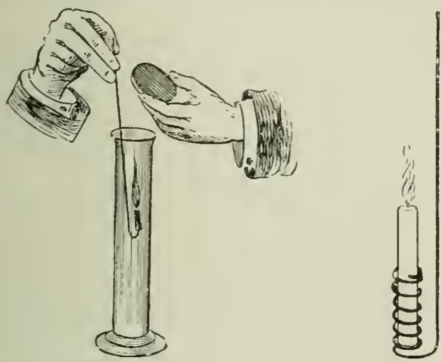

FIG. 56.—Increased Combustion in Oxygen.

jars of oxygen. Notice that it is *not extinguished*, but continues to burn, but with a *brighter*, more intense flame.

Remember that a glowing splinter of wood was rekindled in oxygen.

Action of Oxygen upon Carbon, Sulphur, Iron.—

§ EXPT. 111.—Into a deflagrating spoon put a piece of sulphur in the form of brimstone about the size of a pea, and quickly insert it into another jar of oxygen. (Be careful the wire is drawn sufficiently through the metal plate so that the bottle is tightly covered when the spoon is put in.) Notice that nothing happens even if you wait some minutes. Now take out the spoon, quickly covering the jar with a glass plate meanwhile, and heat it in a laboratory burner until the sulphur melts and has caught fire. Notice that the sulphur burns with a small pale-

blue flame, and gives rise to a smell of "burning sulphur" in the air of the room. Now introduce the deflagrating spoon into the jar of oxygen again. The sulphur immediately begins to burn more vigorously, with a larger, brighter flame, and continues to do so until either the sulphur or oxygen is used up. Keep the bottle and its contents covered up for further examination.

§ EXPT. 112.—Perform a similar experiment with carbon, using it in the form of wood charcoal. Keep the bottle as before.

Oxygen has no effect on substances like sulphur and carbon when they are at the same temperature as the room, but if these elements are heated to the point of ignition, the oxygen *combines* with them very readily, causing them to burn vigorously.

EXPT. 113.—Soften a piece of watch spring (which you can get from a watchmaker) by heating it and allowing it to cool slowly. Pass it through the plate from a deflagrating spoon, and fix it with a piece of a match, so that a suitable length hangs down. Tip the end of the piece of spring with a little sulphur (by dipping it into melted sulphur), and having lighted the sulphur, plunge the spring into a jar of oxygen. The burning of the sulphur heats the end of the spring, and it soon begins to burn brightly, sending off bright sparks. Notice that bright drops fall from the end of the spring, and also that a brown powder collects on the sides of the bottle.

Some substances which will not burn under ordinary conditions can be made to burn in oxygen, and the case of iron affords a good example of this. The student should think of what the result would be if there were only oxygen in the air. As soon as iron got red-hot it would start burning. We could not under these circumstances use iron for our grates, furnaces, and similar things.

Formation of Oxides Explained.—Whenever oxygen combines with another element an oxide is formed. Indeed oxygen is so active and powerful an element that it forms oxides with every element except fluorine.

EXPT. 114.—Select the bottle kept in reserve from Expt. 111. Lift the glass plate and notice the smell of "burning sulphur." Remember the oxygen had no smell, and convince yourself that sulphur has none. Insert a piece of moistened blue litmus paper, and see that it is at once reddened.

EXPT. 115.—Put a burning taper into the bottle saved from Expt. 112, and notice that it is put out. Pour in some clear lime-water, and see that it turns milky.

EXPT. 116.—Compare the globules at the bottom of the bottle and the powder on the side in Expt. 113 with the original watch spring.

In all these cases new substances with new properties have been formed, they are therefore chemical compounds and the experiments afford instances of chemical action. Taking the examples in order, when sulphur burns in oxygen a compound which has a peculiar smell and reddens a blue litmus-paper is formed ; it is called Sulphur Di-oxide.

SULPHUR burning in OXYGEN forms SULPHUR DIOXIDE.

Similarly, when carbon burns in oxygen, a gas which extinguishes a burning taper and turns lime-water milky is formed. This compound is known as Carbon Dioxide.

CARBON burning in OXYGEN forms CARBON DIOXIDE.

Again, when iron burns in oxygen, a brown powder, which is really ordinary iron-rust, is formed, as well as a brittle-black solid quite unlike the original iron. These compounds are both of them oxides of iron.

IRON burning in OXYGEN forms IRON OXIDE.

Other Properties of Oxygen.—Oxygen is not very soluble in water—one hundred parts of water dissolve three parts of this gas. That the amount of oxygen dissolved by water is very small is seen by the fact that we can collect oxygen over water as in Expt. 108. But though the amount is small it is of great importance in the economy of nature, for it is due to this dissolved oxygen that water animals are able to breathe. Though oxygen exists in a gaseous condition under ordinary conditions of temperature and pressure, yet it can, by lowering the temperature and very much increasing the pressure, be made to assume the liquid condition. It is sixteen times as heavy as hydrogen, and a little heavier than the air. It is indispensable to the life of animals. It is the constituent of the atmosphere which is used up in the processes of combustion, decay, and fermentation. Oxygen can, however, be dissolved by some liquids, such as a solution of pyrogallol with caustic potash.

§ EXPT. 117.—Collect some oxygen in a test-tube over mercury. Throw up a little strong solution of pyrogallol and then a small piece of caustic potash. Note that the oxygen is wholly absorbed.

§ EXPT. 118.—Repeat the last experiment, substituting air for oxygen, and notice that the air is only partially absorbed.

Preparation of Hydrogen.—Hydrogen is not very abundant, still it occurs in a great many compounds, such as water and most forms of animal and vegetable substances. It very rarely occurs by itself in any part of the earth. Though hydrogen can be obtained in a variety of ways, all of them very interesting, only two of them need be described here. They are—

(1) By turning hydrogen out of water by means of a metal, *e.g.*, sodium.

(2) By turning it out of sulphuric acid with the help of zinc.

§ EXPT. 119.—Fill a glass trough with water, and invert a cylindrical jar also filled with water in it. Support the cylinder by means of a retort-stand as in Fig. 57. Cut off a small piece of sodium from a lump of the metal (which is kept in mineral oil, because it so easily combines with the oxygen of the air), and place it in a little wire cage with a handle, as shown in Fig. 57. Plunge the cage and sodium into the water, and see that it is placed under the cylinder. Notice that bubbles rise and gradually fill the cylinder with a gas, which is *hydrogen*. Further observe that if we put a reddened litmus-paper into the water it is turned blue.

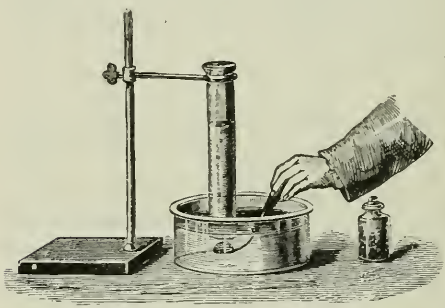

FIG. 57.—Preparation of Hydrogen by throwing Sodium on Water.

The sodium seems to have disappeared, but the fact is that in addition to turning out the hydrogen of the water it combines with what is left, forming a substance called caustic soda, which is dissolved in the water.

SODIUM when thrown into WATER gives CAUSTIC SODA and HYDROGEN.

Hydrogen can also be obtained from water by substituting iron for sodium in the above experiment, but in this case we

have to make the iron red-hot and pass the water over it in the form of steam.

§ EXPT. 120.—Select a flask and fit it up as is shown in Fig. 58. Be very careful that the stopper and the tubes respectively fit very closely. Into the flask put enough granulated zinc to cover the bottom. Pour some water upon the zinc. Arrange the delivery tube in the trough as you did when you were making oxygen. Pour a little sulphuric acid down the thistle-headed acid funnel, and be quite sure that the end of the funnel dips beneath the liquid in the flask. Do not collect bottles of the gas until you are sure pure hydrogen is being given off, which you can find out in this way. Fill a test-tube with water and invert over the end of the delivery tube. When it is

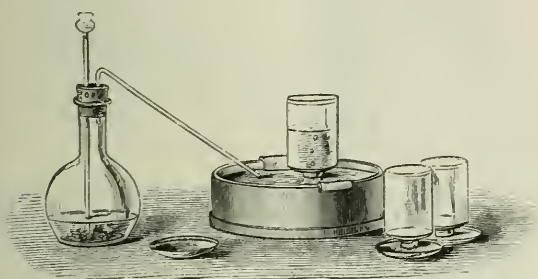

FIG. 58.—Preparation of Bottles of Hydrogen.

full of gas, still holding it upside down, take it to a flame, which should not be near the flask you are using, notice that there is a slight explosion. Continue this until the hydrogen burns quietly down the test-tube. When this happens you may proceed to fill one or two bottles. When the bottles have been filled, it is better not to remove them from the water until you want to use them.

What has happened in this experiment? Zinc and sulphuric acid were put into the flask and hydrogen was obtained. If we evaporate the liquid left behind in the flask after the action is over, we shall have a white crystalline substance called zinc sulphate left behind in the basin.

SULPHURIC ACID when acted upon with ZINC gives ZINC SULPHATE and HYDROGEN.

Properties of Hydrogen.—Examining hydrogen in the same way as we did oxygen in Expt. 109, we find that it, too, is a gas with no colour, no taste, no smell. But in other respects hydrogen is very unlike oxygen.

§ EXPT. 121.—Select one of the jars of hydrogen, and place it on the table in an inverted position with a ground grass plate covering it. Take a lighted taper, to which a piece of stout wire has been attached, in the right hand, and hold it by the wire. Lift the jar of hydrogen off the table with the left hand, still keeping the jar inverted. Quickly pass the lighted taper up into the jar. The hydrogen ignites at the mouth of the jar with a slight explosion, and the taper is seen to have been extinguished. Draw the taper out again, and notice that you can relight it by the flame at the mouth of the jar.

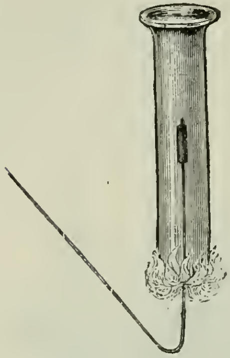

FIG. 59.—Hydrogen burns, but a taper is extinguished by it.

Thus we see that *hydrogen burns in the air, but will not allow a taper to burn in it.*

EXPT. 122.—Remove the glass plate from another of the jars of hydrogen, and keep it off for a minute, and then try to light the gas in the jar. The gas will not burn, for the hydrogen has escaped into the air because of its lightness.

§ EXPT. 123.—Procure a small balloon of gold-beater's skin, and fill it with hydrogen by attaching it to the delivery tube of the apparatus described in Expt. 120. Notice that when tied up with thin silk and released the balloon rises in the air. This is due to the lightness of hydrogen.

§ EXPT. 124.—Counterpoise an inverted beaker hanging from one arm of a balance. Pour hydrogen upwards into the inverted beaker, and notice it becomes lighter and swings upwards. This demonstrates the same property of this gas.

When Hydrogen burns, Water is formed.—

§ EXPT. 125.—Pass hydrogen from a generating flask, such as has been already described, through a U-tube containing lumps of calcium chloride, which has the power of taking up any moisture, along a tube drawn out to end in a narrow opening, as shown in Fig. 60. When

quite sure pure hydrogen is being given off, set fire to it. Place a bell or some other jar over the flame as shown, and notice that drops of

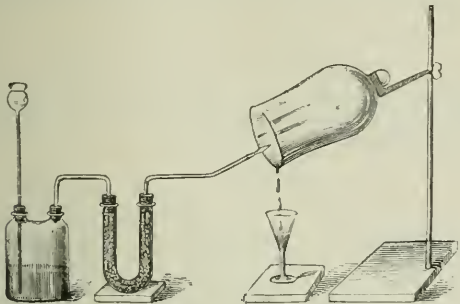

FIG. 60.—When Hydrogen burns, Water is formed.

water condense on the sides of the jar, and can be collected in a glass.

Because of its Lightness, Hydrogen can be collected by upward displacement of Air.—

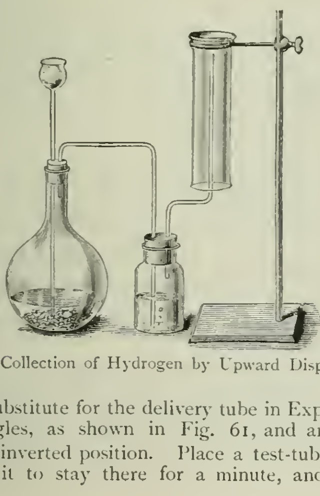

FIG. 61.—Collection of Hydrogen by Upward Displacement.

EXPT. 126.—Substitute for the delivery tube in Expt. 120 a tube bent twice at right angles, as shown in Fig. 61, and arrange a jar on a retort-stand in an inverted position. Place a test-tube over the upright tube, and allow it to stay there for a minute, and test the gas as

described in Expt. 120. When it is pure substitute the inverted jar, and after a few minutes lift it off the stand and apply a light, first taking the precaution to wrap a duster round the jar and to hold it away from your face. The jar will be found to contain hydrogen.

Chief Points of Chapter VIII.

A Chemical Element is matter which cannot by any known methods be broken up into a simpler form, or from which two different substances cannot be obtained.

Substances

- Elements
  - Metals
  - Non-metals
- Compounds, elements present in definite proportions
- Mixtures, constituents present in any proportion.

Oxygen.—Occurrence: Forty-eight per cent. of earth's crust by weight; in water, eight-ninths by weight; in air (uncombined), one-fifth by volume. Made by heating a compound containing it, *e.g.*, mercuric oxide or potassium chlorate. Is a gas, without colour, taste, or smell, and a good supporter of combustion. Unites with all elements except fluorine to form oxides. Slightly soluble in water.

Hydrogen.—Occurrence: Almost entirely in combination, as in water and in most animal and vegetable substances. Set free (1) by the action of sodium upon water; (2) by the action of zinc upon dilute sulphuric acid; (3) by the action of red-hot iron filings upon steam. Is the lightest gas known, and has no colour, taste, or smell. Is inflammable, but will not support combustion. Unites with oxygen to form water.

Questions on Chapter VIII.

(1) Describe an experiment to illustrate the difference between a mixture and a chemical compound.

(2) How would you show that gunpowder is a mixture of three substances?

(3) If you had three bottles or jars filled with oxygen, what experiments would you perform to illustrate characteristic properties of the gas?

(4) What is an oxide? Name two oxides, and state how you could make them in the laboratory.

(5) Describe an experiment to make hydrogen.

(6) If you were given three bottles of hydrogen, what experiments would you perform to illustrate characteristic properties of the gas.

(7) Describe an experiment to make oxygen.

CHAPTER IX

COMMON CHEMICAL ELEMENTS AND COMPOUNDS.

Water.—It has already been shown that water is a binary compound, and is formed when hydrogen burns, and that when substances burn in the air they do so by combining with oxygen which is contained therein. These facts alone indicate that water contains hydrogen and oxygen, or is, as we have learnt to say, an oxide of hydrogen. But it will be well now to see how it can be proved that water is a compound containing *only* oxygen and hydrogen, and also in what proportion these elements combine to form water.

Analysis and Synthesis.—The task we have set ourselves can be done in two ways—either we can start with water and proceed to split it up into oxygen and hydrogen, or starting with these elements they can be made to combine to form water. If the first method is adopted the *analysis* of water will have been effected, whereas if water is built up from oxygen and hydrogen, its *synthesis* will have been performed. *Analysis is the splitting up of a compound into its constituents; by synthesis is meant that the compound has been built up from its constituents.*

Analysis of Water.—Water can be split up into oxygen and hydrogen by means of the electric current.

§ Expt. 127.—This experiment is performed by the help of a battery for generating the electric current and a *voltameter* for containing the water. The construction of the voltameter will be readily understood by reference to Fig. 62. It is seen to consist of a glass bowl, over the sides of which hang two wires, with small plates of platinum attached to the ends. The platinum plates dip down into the water as

shown. Over the plates are supported two tubes of exactly equal size and closed at the top. The tubes and part of the bowl are filled with water, to which has been added a little sulphuric acid to make it conduct the electric current easily. The wires from a battery of three or four cells are suitably connected with the wires which hang over the sides of the bowl. As soon as the connection with the battery is complete, provided there is clean metal at every junction, bubbles of gas are seen to rise from each platinum plate, and to rise up into the tube and collect there above the liquid. After the experiment has gone on for half-an-hour, it will be noticed that twice as much gas has collected in one tube as in the other, and it will be found by testing the gases that the gas of which there is the larger amount burns and is hydrogen, while the other gas rekindles a glowing splinter and is oxygen, the element which hydrogen takes out of the air when burnt therein (*see* Expt. 125).

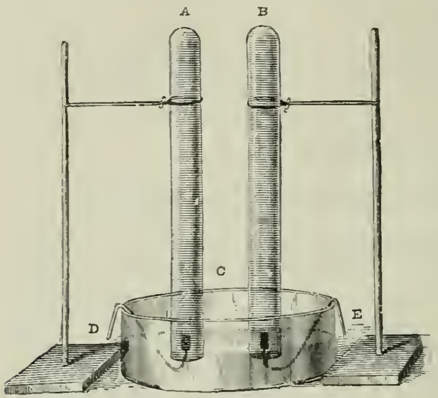

FIG. 62.—A Voltameter for the Analysis of Water.

Synthesis of Water.—For this purpose a piece of apparatus called a *eudiometer* is required. In its simplest form a eudiometer consists of a long glass tube closed at one end and marked down the sides in divisions of equal size, usually cubic centimetres. Through opposite sides of the tube at the closed end pieces of platinum wire are passed and fused into the glass, being so arranged that they do not quite touch one another inside. Outside the tube the platinum is bent into a loop so that wires may be easily attached.

To use the eudiometer it is first completely filled with mercury and inverted in more mercury contained in a trough. A suitable amount of pure dry hydrogen is then bubbled into the tube, and afterwards there is passed into it, in a similar way, exactly one-half of this amount of pure dry oxygen. Suppose twenty divisions of hydrogen had been taken we should add to it ten divisions of oxygen, and should thus

obtain thirty divisions of the mixture. The eudiometer is then made to press upon a sheet of india-rubber upon the bottom of a trough, and the gases are made to combine by causing an *electric spark* to pass between the platinum wires inside the tube. As soon as the spark passes, the two gases combine with a flash. The wires from the Leyden jar or induction coil, which we use to get the spark, are now disconnected from the eudiometer, which is left to cool. The inside of the tube will be seen to be moist. The eudiometer is now raised off the bottom of the trough, taking care not to lift it above the surface of the liquid, and at once the mercury is seen to rise up and completely fill it.

The two elements have combined to form the moisture which was observed. If there is no gas left over, the oxygen and hydrogen have evidently been mixed in the exact proportions in

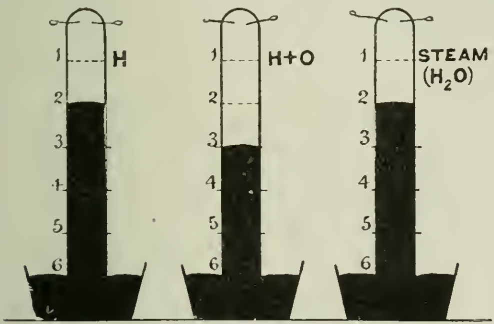

FIG. 63.—Synthesis of Water.

which they combine to form water. Now, if instead of allowing the eudiometer to cool, it had been surrounded with a large closed tube, through which steam was continually passed, we should have found that, after the electric flash, the thirty divisions had contracted to twenty, and as the gas occupying this space condenses to water, if allowed to cool, we have learnt

20 divisions of Hydrogen	combine with	10 divisions of Oxygen	to form	20 divisions of Steam

or, writing it in another way, *two parts of hydrogen by volume combine with one part of oxygen by volume to form water, and no gas is left over.*

Composition of Water by Weight.—

§ Expt. 128.—Heat some copper turnings or a roll of copper gauze to redness in a hard glass tube through which air is being drawn. Notice that it becomes black, and by weighing, before and after, see that there is an increase in weight of the contents of the tube. The copper has taken something out of the air, which we have learnt is oxygen, and has become changed into copper oxide.

§ Expt. 129.—Pass hydrogen, prepared as in Expt. 120, over some of the blackened copper or copper oxide, and observe that steam is produced and may be condensed into water by passing through a cold tube. The copper oxide is meanwhile changed back to copper. Notice incidentally that air contains one of the constituents of water, viz., oxygen.

Up to the present we have concerned ourselves only with the composition of water by *volume*. This has been proved both by analysis and by synthesis. If, however, we wish to know the weights of oxygen and hydrogen which combine to form water, a different method has to be followed. Pure dry hydrogen is passed over heated copper oxide, as in Expt. 129. The hydrogen takes out the oxygen, combining with it to form water, and leaves the copper behind. Evidently, if the amount of copper oxide used is weighed, and also the amount of copper left, the difference between the two weighings gives the weight of oxygen which combines with hydrogen. The water formed is weighed too, therefore, to get the weight of hydrogen, all we have to do is to subtract the weight of the oxygen from that of the water. In this way it has been found that 100 parts of water by weight contain 88·89 of oxygen and 11·11 of hydrogen, or very nearly sixteen of oxygen and two of hydrogen.

Properties of Water.—As every one knows, water is, at ordinary temperatures, a liquid. It is never found pure in nature. The purest water which occurs naturally is rain-water, collected after it has rained for some time. In thin layers it has no colour, but anybody who has seen a clear mountain lake will know that deep water has a lovely blue colour. When pure it has no taste and no smell. The student has already learnt that its behaviour when cooled forms an exception to the general rule, and by re-reading Chapter VI. he will remind himself of the change it undergoes as its temperature is raised. A simple experiment will prove it to be a bad conductor.

§ Expt. 130.—Put a piece of ice in the bottom of a long tube, weight it down with a piece of lead. Add water above. Hold obliquely and boil the water at the top over a Bunsen flame without melting the ice.

Water does not become hot by conduction in the ordinary ways of heating, as, for instance, in boiling water in a kettle over a fire. In such cases the particles of water which are lowest first become heated. They expand, get lighter bulk for bulk, and rise. Thus currents are formed, the warmed particles rise, and their place is taken by colder ones from the top. This process, we have learnt, is known as *convection*, while the currents are referred to as *convection-currents* (*see* p. 82).

Water is contained in many crystals, and since the crystalline form of these compounds depends upon this water it is known as *water of crystallisation*.

§ EXPT. 131.—Exhibit crystals of blue vitriol. Powder one and heat the powder in a dry test-tube, and show that water collects on the sides of the tube. The blue vitriol becomes white as it loses water. Dry a larger quantity of blue vitriol in an oven till white. Pour water upon some of the white powder thus formed. Notice it regains its original blue colour with the evolution of heat.

Water as a Solvent.—If a piece of sugar is put into water it soon disappears, and the liquid is found to be sweet in every part. The sugar has *dissolved* to form a *solution* of sugar. Similarly, a very great number of substances dissolve in water, but not all to the same extent. Those substances which dissolve in this manner are called *soluble*, while those which do not are spoken of as *insoluble*.

§ EXPT. 132.—Weigh out an ounce each of sugar, common salt, and powdered gypsum. By increasing the amount of water ascertain how much is necessary to completely dissolve each of the powders. Show the amounts of water are roughly 1 ounce, 3 ounces, and 360 ounces ($2\frac{1}{4}$ gallons) respectively.

Water dissolves a larger number of things than any other liquid, and is in consequence of the greatest use to chemists. This explains why we cannot find pure water in nature. No sooner has the rain formed than it begins to dissolve various substances; in its passage through the air it takes up varying amounts of the constituents of the atmosphere, such as carbon dioxide and oxygen, and when the surface of the earth is reached the water dissolves out of the soil and the underlying rocks portions of all the soluble ingredients. The more soluble bodies are naturally dissolved to the largest extent. It will be seen later that the solvent property of water is considerably increased

by the presence of the carbon dioxide it obtains in part from the air. When the amount of material dissolved in water is very great it gives a distinctive character to the liquid, which becomes known as a *mineral water.* Those natural waters which contain a compound of sulphur and hydrogen, called sulphuretted hydrogen, are spoken of as *sulphur-water*, if some compound of iron is the substance which has been taken up in large quantities, we have *chalybeate* waters formed. *Effervescent* waters have a great amount of carbon dioxide dissolved.

§ EXPT. 133.—Boil out the gas from common water and show that its chief ingredient is carbon dioxide (*see* p. 134).

Hard and Soft Waters.—It is a fact familiar to every one that soap lathers very easily in some waters and not at all in others. If rain-water be used, the lathering takes place with great ease, while with the water which is supplied to some towns a lather can only be made with difficulty; and if we attempt the same process in sea-water there is no lathering at all. *Those waters in which soap lathers easily are said to be soft. When this is not the case the water is spoken of as hard.* The explanation is a simple one. Water, as we have seen, dissolves materials out of the rocks below the soil, and often takes up, among other things, compounds of calcium and magnesium, which unite with soap forming a new compound of an insoluble kind, and in consequence there is no lathering until all the calcium and magnesium has thus combined with soap, after which the solution or lathering of the soap begins. The soap which combines with the dissolved materials is, of course, wasted.

Temporary and Permanent Hardness.—Hard waters differ among themselves. Some can be softened by mere boiling, and when this is the case the hardness is said to be *temporary.* If the hardness is not removed after the water has been boiled, and the water requires the addition of a chemical to soften it, such hardness is termed *permanent.* As has been already mentioned, the presence of carbon dioxide in water gives it the power of dissolving substances which would be otherwise insoluble. Chalk, known to chemists as calcium carbonate, is insoluble in pure water, but in water in which there is carbon dioxide it dissolves to a considerable extent. As soon as this dissolved gas is got rid of, which can be done by boiling, the chalk, being no longer soluble, is thrown down upon the sides of the vessel. It forms in this way the incrustation which is found on the inside of kettles and boilers.

Permanent hardness is due to the presence of dissolved calcium sulphate and other compounds. Since this substance is soluble in pure water, mere boiling will not get rid of it; washing soda, which is a form of sodium carbonate, softens such water as this, by causing the formation of calcium carbonate in the place of the calcium sulphate.

Distillation of Water.—If the steam which is formed by boiling water containing any of these dissolved substances be condensed, the water formed is quite pure. To obtain pure water from any kind of water, then, whether fresh or salt, all that has to be done is to boil it and condense the steam which is given off. The dissolved materials are all left behind in the

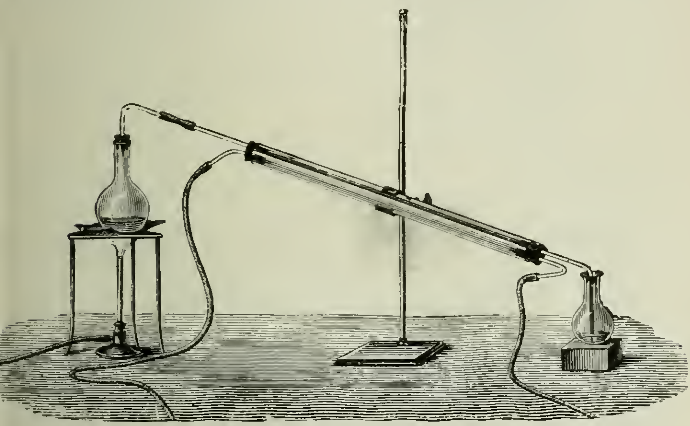

FIG. 64.—The Distillation of Water.

vessel in which the boiling takes place. An arrangement for condensing steam or vapour is shown in Fig. 64. The steam that is driven off from the water in the flask passes through a long tube kept cool by being surrounded with water, and is thus condensed.

§ EXPT. 134.—Evaporate a little distilled water in a platinum or porcelain crucible. Notice the absence of any residue. Repeat the experiment with tap-water, and note the residue.

Amount of Dissolved Material in Natural Waters.—This depends upon the kind of rocks over which the water

has flowed. If the supply of water comes from a district where the rocks are hard and insoluble, such as granite, the amount of material dissolved will be very small. Thus, the water of the Dee, near Aberdeen, which flows over a country of this kind, contains only three grains of dissolved salts to the gallon, weighing 70,000 grains. The amount dissolved in the same quantity of Thames water at London Bridge is seen from the following table[1] :—

Calcium carbonate	8·12
Calcium chloride	6·97
Sodium sulphate	3·11
Sodium chloride	2·37
Potassium sulphate	·30
Silica	·12
Magnesium chloride	·08
Organic matter	2·39
	23·46

Nitrogen.—The fact that air contains nitrogen has already been learnt, and we shall show by an experiment in this section that, as nearly as possible, air contains four-fifths of its volume of this gas. This element also occurs in a class of compounds called *nitrates*, some of which are found in nature, *e.g.*, nitre or saltpetre, known to chemists as potassium nitrate, and a similar compound of sodium, Chili saltpetre. It helps to form ammonia; and is also present in most of the compounds building up plants and animals.

Preparation of Nitrogen.—This gas is most easily got from air by removing the oxygen contained therein.

EXPT. 135.—Float a small evaporating basin upon water contained in the pneumatic trough. Carefully cut off a piece of phosphorus as large as a good-sized pea, dry it, and place the lump in the basin. The cutting should be done under water. Ignite the phosphorus and place over it a bell jar from which the stopper has been removed, and which has been divided as nearly as possible into five parts by pieces of paper gummed outside. Let the bottom of the jar either rest on the shelf of the trough or on something suitable placed on the bottom. Insert the stopper

[1] Adapted from "Analysis of Thames Water," by John Ashley. *Quart. Journ. Chem. Soc.* vol. ii. p. 74.

quickly. Allow the apparatus to remain for five minutes, when the white fumes will have disappeared, and the water will be seen to have risen up to the level of the first division so as to fill one-fifth of the jar.

Properties of Nitrogen.—The gas which remains in the jar in the last experiment, and which occupies four-fifths of the jar, is nitrogen. We can readily convince ourselves that it has no taste, no colour, no smell, and does not act upon litmus-paper. It extinguishes a taper. It will not burn; nor will it turn lime-water milky. A mouse dies if put into the gas. In short, it has no active properties at all.[1] If the negative nature of the properties of nitrogen is borne in mind, and if we think of this side by side with the very active powers of oxygen, we shall understand that its presence in the air serves the purpose of diluting the oxygen, weakening its powers, and making combustion much less intense.

§ EXPT. 136.—Prepare samples of nitrogen, and show (1) that it extinguishes a lighted candle; (2) it will not turn lime-water milky when shaken up with it.

§ EXPT. 137.—Mix four volumes of nitrogen with one volume of oxygen, show that there is no contraction or other manifest change, and that a candle burns in the mixture as in common air.

CARBON, IRON, AND MERCURY

Carbon.—This element is a non-metal which is solid at ordinary temperatures. It is very abundant in nature, occurring in all *organic* compounds, that is, those which help to build up the substance of plants and animals. It is found, too, in a large class of mineral bodies known as *carbonates*, the most familiar of which, calcium carbonate, makes up limestone, chalk, and marble, as well as other less important substances in the earth's crust.

Carbon is known to chemists in a variety of forms. Whenever the same element assumes forms with physical properties which are quite different, it is said to form an example of *allotropy* or to have several *allotropic forms.*

Allotropic Forms of Carbon.[2]—Some of the varieties of carbon are *crystalline*, while others have no definite shape or

[1] Nitrogen has recently been shown to combine at a red heat with magnesium, lithium, barium, aluminium, zinc, iron, copper.

[2] The teacher should exhibit the various allotropic forms of carbon.

are *amorphous*. The two kinds of carbon which occur as crystals are *diamond* and *graphite*. Carbon of an amorphous kind is known to us as *charcoal*, that obtained from animal sources being called *animal charcoal*, or, since it is usually derived from bones, *bone black*, while the other sort, obtained from wood, is spoken of as *wood-charcoal*. There are one or two other more or less impure varieties, such as *lamp-black*, *soot*, and *coke*.

Diamond.—This form of carbon is the purest known. It is familiar to every one as a beautiful jewel, remarkable for its splendid lustre as well as for its high refractive power. It is the hardest body known, being able to scratch everything else. It is found in nature among the oldest rocks, often having the form of the solid known as the *octahedron*, which has eight sides. It is found in India, Borneo, Brazil, and South Africa. If in Expt. 112 we had substituted a diamond for the charcoal we should have found that it would have burnt completely away, forming only carbon dioxide.

Graphite.—This is sometimes called *plumbago* and sometimes *black-lead*. It has an almost black colour, and looks very like a metal. It is soft enough to be used as pencils to mark paper. Like the diamond, it forms carbon dioxide when burnt in oxygen. It is found in our country in large quantities at Borrowdale.

Charcoal.—Both animal- and wood-charcoal are very porous substances, and they have the power of absorbing gases to a large extent. Wood-charcoal is used considerably on the continent for heating purposes. Both kinds are useful in destroying noxious vapours, and are valuable, too, for filtering liquids through.

Whenever any of the amorphous kinds of carbon burn, carbon dioxide is the compound formed.

EXPERIMENTS WITH WOOD-CHARCOAL.—

§ EXPT. 138.—Heat strongly a piece of charcoal in a closed hard glass test-tube and show that without air it does not burn.

§ EXPT. 139.—Suspend a piece of glowing charcoal in a bottle containing lime-water. Shake up and show that lime-water is turned milky owing to formation of carbon dioxide.

§ EXPT. 140.—Show that charcoal floats in cold water. In boiling water charcoal sinks after a time, and then will not float again unless thoroughly dried.

§ EXPT. 141.—Fill a large test-tube with ammonia gas over mercury, and show that it can be absorbed by introducing a small lump of charcoal.

Carbon Dioxide.—It has already been said many times that, when carbon in different forms is burnt, carbon dioxide gas is formed. It will now be desirable to study this compound more fully. The gas is found to a certain extent in the air at all times, and in neighbourhood of volcanoes it is often very abundant. Many mineral waters, such as the waters of Pyrmont and the Selters, contain large quantities of it dissolved.

This compound also forms part of all carbonates.

Preparation of Carbon Dioxide.—To prepare this gas, it is only necessary to act upon some pieces of marble with an acid, such as hydrochloric acid.

§ EXPT. 142.—Fit up the same apparatus as was used in Expt. 120; substitute pieces of marble for the zinc there used, and having covered the marble with water, pour strong hydrochloric acid down the acid funnel till the action is quite brisk. The gas is so much heavier than air that it is allowed to pour down the delivery tube into a jar as shown in Fig. 65. Collect several jars of the gas.

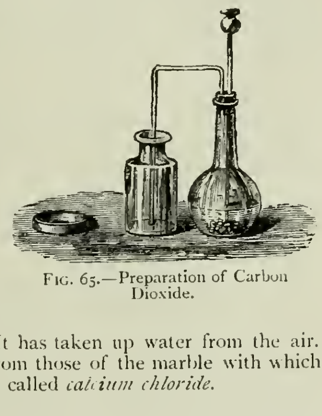

FIG. 65.—Preparation of Carbon Dioxide.

EXPT. 143.—Pour off some of the liquid remaining in the flask from the last experiment, and if necessary filter it. Evaporate to dryness in a basin as previously described, and observe the soft white solid left behind. Leave the residue thus formed exposed to the air, and examine a few hours later. It will be seen to be quite wet. It has taken up water from the air. Its properties are quite different from those of the marble with which we started. This new compound is called *calcium chloride.*

We can represent this preparation of carbon dioxide as follows:—

MARBLE	when acted upon by	HYDROCHLORIC ACID	gives	CALCIUM CHLORIDE	and	CARBON DIOXIDE.

Carbon dioxide can also be prepared by heating a carbonate such as magnesium carbonate or calcium carbonate.

§ EXPT. 144.—Heat magnesite, which is a naturally occurring magnesium carbonate, in a hard test-tube, and show that carbon dioxide is given off.

Properties of Carbon Dioxide.—Carbon dioxide is an invisible gas possessing neither taste nor smell, is soluble in water, and it is a remarkable circumstance that whatever the pressure to which the gas is subjected, water will dissolve almost exactly its own volume. Let us make this quite clear. Suppose we take a pint of water and a pint of carbon dioxide at the ordinary temperature and pressure of the air; the pint of water will just dissolve the pint of gas. If now the carbon dioxide is compressed so that, instead of measuring a pint it measures only half this amount, then half a pint of water will be sufficient to dissolve it.

As was shown in Expt. 115, carbon dioxide will not allow things to burn in it. If the gas is passed into lime-water a milkiness is at once produced, but if the operation is continued the turbidity disappears. As has been already shown, the milkiness is due to the formation of chalk, and the reason why the solution becomes clear by dissolving more gas is that chalk is soluble in water containing carbon dioxide.

§ Expt. 145.—Perform the experiment described above. After causing the solution to become clear, boil it for some little time, and notice that the chalk is again thrown down.

Carbon dioxide is much heavier than air, and can in consequence be easily poured from one vessel to another like a liquid.

§ Expt. 146.—Show that carbon dioxide is heavier than air by pouring from one vessel to another, and by testing the gas in the second vessel with a lighted candle. Show the flame is extinguished.

Carbon Dioxide dissolved in Water acts as an Acid.—When this compound is dissolved in water it is found that it has weak acid properties. This can be proved by putting a blue litmus-paper into the solution and observing that the paper is reddened. All acids have this property of turning blue litmus into red. By the combination of carbon dioxide with a class of compounds represented by lime-water and called *bases*, we get a series of *salts* formed, known as carbonates, as, for instance, the chalk in Expt. 145.

Acids, Bases, and Salts.—A sufficient number of elements and compounds has now been studied to make the student able to understand the meaning of these terms, which we shall have

occasion to use more often later on. The name acid is given to those substances which have a sour taste, turn blue litmus-paper red, and cause carbon dioxide to be given off when added to a carbonate. They always contain hydrogen, which they give up when acted upon by another set of compounds, the bases. An exchange is effected. The base always contains a metal, and this metal takes the place of the hydrogen of the acid, changing the acid into a salt and the base into water.

AN ACID	acted upon by	A BASE	forms	A SALT	and	WATER.

The bases have properties which are the reverse of those possessed by the acids. When the two come into contact, they *neutralise* one another, and the compound which results is a neutral one—it has no action upon litmus-paper. If the base is soluble in water, it is called an *alkali*. The alkalis have a soapy taste, turn red litmus blue, and combine with carbon dioxide.

§ EXPT. 147.—Obtain specimens of caustic potash and caustic soda. Make solutions and show that they have the power of turning red litmus-paper blue. Add a little hydrochloric acid, drop by drop, to a portion of one of these alkalis, and show that a point is reached when the resulting solution has no action on litmus. The acid neutralises the alkali.

Iron.—Iron is by far the most important metal known to man. The discovery of how to obtain it from the minerals in which it occurs was probably the most valuable ever made. Though it is very abundant in nature, it is rarely found uncombined. It has been found in certain strange masses, called meteorites, which drop upon this planet from inter-stellar space. In the earth it is found combined with oxygen, forming oxides as *magnetite* and *hæmatite*; as oxides combined with water in *limonite* and *gothite*; with sulphur, as the sulphides, *iron pyrites*, and *magnetic pyrites*; with carbon dioxide as the carbonates, *clay iron-stone*, and *chalybite*; and other less important ores. It would be outside the scope of Physiography to describe how the metal is obtained from these minerals, and we must content ourselves with referring the student to some book on Chemistry or Metallurgy for a full treatment of the subject.

Three Kinds of Iron.—Iron is known and used in three forms, *wrought-iron*, *cast-iron*, and *steel*. The first is almost the pure element, but cast-iron contains also varying amounts of carbon and silicon. Steel contains the same elements as cast-iron, but the amount of carbon is considerably smaller. The different uses to which these varieties of iron are put depends upon the difference in properties they possess.

Wrought-iron is very tough, and can easily be beaten out into plates—a property spoken of as *malleability*. For those articles which are made by hammering the iron into shape, wrought-iron will evidently be used.

Cast-iron is, on the other hand, brittle and easily melted, and consequently is employed in all cases where the article is made by running the molten metal into moulds.

Steel has different properties according to the processes through which it has passed. If it has been heated and then cooled very quickly it is extremely hard but very brittle; but if cautiously heated and cooled very much more slowly, it is no longer brittle but elastic. This latter process is called *tempering*. Another very important property which steel possesses, and which has come before our notice already, is that steel can be made into a magnet, which will keep its magnetism for a very long time.

All the magnetic needles used in telegraphing and in electrical instruments of other kinds are made of steel. We shall return to the subject in Chapter XXI. The densities of different kinds of iron are seen from the following table:—

Steel, not hammered	7·816
Iron, bar	7·788
Iron, cast	7·207

§ EXPT. 148.—Determine the specific gravity of different kinds of iron as explained on p. 23.

It will be noticed that the density of steel is greater than that of iron. Iron does not combine with oxygen to form an oxide in dry air at ordinary temperatures. But if the air is moist, more especially if it contains carbon dioxide, the iron is easily acted upon, and *iron-rust*—which is an oxide of iron combined with the elements of water—is formed.

§ EXPT. 149.—Weigh carefully a capsule containing about ten grams of iron filings. Moisten with water and dry again in an oven; repeat the moistening and drying several times till the iron is very rusty, then show that there is an increase of weight.

Or, if the iron is heated in dry air combination takes place between the two elements; the oxide formed, however, in this case, is not the same as iron-rust, but a black substance, taking the form of scales. We have learnt before (Expt. 113) that iron can be made to burn in oxygen, forming the same black compound which contains the same proportions of iron and oxygen as magnetite. Iron can be made to turn hydrogen out of water by adopting different means from those used with sodium in Expt. 119. The iron must be used in the form of filings

which are made red-hot, and the water drawn over them in the form of steam (*see* p. 118). The oxygen unites with the iron and the hydrogen passes on.

Oxides of Iron.—Iron combines with oxygen in several proportions. The following table shows the proportions of the iron and oxygen present in each case :—

	Parts by weight.		
Iron Monoxide or Ferrous Oxide	56 of Iron with	16 of Oxygen.	
Iron Sesqui-oxide or Ferric Oxide	112 ,,	48 ,,	
Black Iron Oxide or Tri-ferric Tetroxide	168 ,,	64 ,,	

The first of these does not occur in nature as a mineral. It combines with acids forming the series of salts known to chemists as *ferrous* salts, one of which, *ferrous sulphate*, is known naturally as the mineral *copperas*.

The second, ferric oxide, is fairly abundant in nature. It constitutes the beautifully crystallised mineral *specular iron ore*, found in Elba. It also makes up the mineral hæmatite, which goes under the names of *kidney ore* and *pencil ore* in the Furness district of Lancashire, according to the shapes which it assumes. It serves as a very valuable source of iron, the noted Barrow steel being derived from it. It is also found in many other parts of Great Britain and other countries.

The black oxide may be regarded as being formed by the combination of the other two. It constitutes the minerals *magnetite* and *lodestone*. It is very often magnetic, though by no means always. It was the magnetic properties of this substance which first made the force of magnetism known to man.

Mercury.—Mercury or quicksilver is the only metal which is liquid at ordinary temperatures. Its appearance is familiar to every one from its frequent use in barometers and thermometers. It sometimes occurs pure in nature, or, as mineralogists say, *native*. Chiefly, however, it occurs in combination with sulphur as the mineral *cinnabar*, which is found in Spain, Hungary, Tuscany, and South America. If it be cooled to a temperature of -40° C. it solidifies and is then malleable. It is the heaviest liquid known, being $13\frac{1}{2}$ times as heavy as water.

§ EXPT. 150.—Determine the density of mercury by the specific gravity bottle.

If it be heated to a temperature of 315° C. and air be passed over it, it combines with oxygen, forming the red oxide of mercury which we used in Expt. 107 to prepare oxygen. It boils at $357^\circ\!\cdot\!25$, and is converted into a transparent, colourless

vapour, which is very poisonous. It dissolves many metals, *e.g.*, tin and lead, forming alloys known as *amalgams.*

Not only is it used in barometers and thermometers, but also in the manufacture of looking-glasses and in the laboratory instead of water over which to collect some of the gases which are soluble in water.

Experiments with Mercury.—We can show that mercury is between thirteen and fourteen times as heavy as water, not only with the specific gravity bottle as in Expt 24, but also as follows :—

§ EXPT. 151.—Bend a piece of narrow glass tube in the middle, so that the two branches are parallel to each other and each is about two feet long. Fill the bend with mercury, and then pour water into one side ; when the mercury has risen one inch on the opposite side the column of water will be thirteen or fourteen inches high.

§ EXPT. 152.—Take a glass bowl of mercury. Notice that it does not wet the glass. Small iron objects float on it.

§ EXPT. 153.—Rub mercury on a piece of clean zinc or copper, and see that the mercury adheres and forms an amalgam.

Familiar Binary Compounds.—Several of the compounds made up of two elements, which we have learnt to call binary, have already been described, and in one case, water, we have become acquainted with all those properties which will be of assistance to us in understanding other parts of our subject. In this section we intend to deal with two common oxides, silica and lime, the first a compound of oxygen with silicon, the latter of the same element with calcium ; and a chloride (common salt) made up of sodium and chlorine.

Crystalline Silica.—The table on p. 112 gives the percentage of the element silicon in the earth's composition as 29. If we consider the oxide silica, we find the amount per cent. of it occurring is very much greater, reaching the high number of 61·7. It is found in large quantities as more or less pure silica, as well as abundantly in combination as silicates, which are salts formed by the union of bases with silica, which acts as an acid. It is sometimes crystalline, at others amorphous. Two crystalline varieties are known, one, *tridymite*, is unimportant, while the other, *quartz*, is a frequently-occurring and highly-interesting mineral. If the quartz is quite clear and transparent, it is known as *rock-crystal*, and is the *Brazilian pebble* from which lenses are made

for eye-glasses, &c. Sometimes the oxide of a heavy metal is present, colouring the quartz. If it has a purple tint, for example, it goes by the name of *amethyst;* if brown, *cairngorm;* if yellow, *citrine.*

Many *sands* are made up entirely of grains of quartz which have become more or less rounded by continual rubbing against one another in water. If the sand becomes compacted by the introduction of a cement and by the action of great pressure a *sandstone* is formed.

Amorphous Silica.—This is found in the form of (1) chalcedony and its varieties, (2) jasper and its varieties, (3) opal.

Chalcedony is known having all sorts of tints. It is often regarded as a mixture of quartz and opal ; it is familiar as the well-known red stone used in signet-rings and called *carnelian. Heliotrope* is a green variety speckled with red. *Agate* is a variegated chalcedony, composed of different coloured bands. *Flint* is generally of a black or dark gray colour, and is found in nodules or bands in the chalk formations of Surrey, Kent, &c. *Onyx*, *sardonyx*, *chrysoprase*, are other forms.

Jasper is an opaque, impure form of silica, of a red, brown, or yellow colour. *Egyptian* or *ribbon jasper* is a beautifully banded variety with different shades of colour.

Opal.—This species of naturally occurring silica always contains water in varying amounts. It is supposed to contain some quartz as well as amorphous silica. It is often used in jewellery ; one variety shows a well-developed iridescence, and is called *precious opal.*

§ EXPT. 154.—Exhibit as many of the above varieties of silica as possible. Show their insolubility in water and in acids.

§ EXPT. 155.—Obtain some "soluble glass." Show its partial or complete solubility in water and the separation of gelatinous silica by strong acids.

Lime or Calcium Oxide.—This does not occur pure naturally. It is manufactured on a large scale for many purposes by strongly heating the compound which it forms with carbon dioxide or calcium carbonate (*see* Expt. 145). Calcium carbonate is found in the earth as limestone, chalk, marble, calcite, aragonite, &c. ; it also makes up the shells of animals

like oysters, whelks, and others, popularly referred to as shell-fish. Generally, lime is obtained by *burning* limestone in kilns. This burning of lime, as it is called, means simply strongly heating it, with the result that the limestone is broken up into two components, the lime which is left behind and the carbon dioxide which is driven off as a gas.

CALCIUM CARBONATE	when strongly heated gives	LIME	and	CARBON DIOXIDE

The same decomposition takes place if any of the forms of calcium carbonate mentioned are strongly ignited.

When water is added to freshly-burnt lime, the water combines with it with the evolution of a large amount of heat, which is enough to boil the water if the quantity of lime is large. This can be seen at any time when bricklayers are preparing the lime for making mortar. This addition of water to lime is called *slaking* it. Lime dissolves to some extent in water, forming lime-water.

§ EXPT. 156.—Pour about three ounces of water upon half a pound of good lime. Observe the evolution of heat and formation of a dry compound.

§ EXPT. 157.—Mix some of the compound formed in the last experiment with more water, and show that the lime-water turns a red litmus-paper blue, or the solution is alkaline.

When strongly heated, lime becomes very luminous, and on this account is used in the oxy-hydrogen lantern, where the intense heat resulting from the combination of hydrogen and oxygen is made to raise the lime to so high a temperature that it becomes beautifully luminous.

Lime acts as a base. When made to neutralise sulphuric acid it forms a salt called *calcium sulphate*, which, as we have seen, often occurs in water, making it permanently hard. The same compound is known under the forms of *gypsum* and *plaster of Paris*. By its combination with *phosphoric acid* lime forms *calcium phosphate*, which helps largely to build up bones.

§ EXPT. 158.—Dissolve some pure lime in hydrochloric acid. Show the solution is identical with that obtained in Expt. 142.

Sodium Chloride or Common Salt is found in beds of different thickness in the earth, under the name of *rock-salt*.

It crystallises in cubes. The largest amount is found in the salt-mines of Austria. In this country rock-salt is obtained most abundantly from Cheshire. It is present in large quantities in sea-water mixed with other compounds, as we shall learn later. It is soluble in water, though one part of sodium chloride by volume requires two and a half parts of water to dissolve it, and, as is but rarely the case, warm water will dissolve no more than cold water. It is used largely to prevent decomposition of meats of all kinds. Enormous quantities are consumed in this country in the manufacture of sodium carbonate.

Chief Points of Chapter IX.

Composition of Water.—Water is composed of two elements—hydrogen and oxygen—in the proportion of two volumes of the former to one of the latter.

Analysis

$$\text{Water}\ \left.\begin{array}{l}\text{when traversed by}\\ \text{an electric current}\end{array}\right\}\ \text{breaks up into}\ \left\{\begin{array}{c}\text{Hydrogen}\\ (2\text{ vols.})\end{array} + \begin{array}{c}\text{Oxygen}\\ (1\text{ vol.}).\end{array}\right\}$$

Synthesis.

$$\left.\begin{array}{c}\text{Two volumes}\\ \text{of hydrogen}\end{array}\right\}\ \text{unite with}\ \left\{\begin{array}{c}\text{One volume}\\ \text{of oxygen}\end{array}\right\}\ \text{to form Water}$$

$$\left.\begin{array}{c}\text{2 parts by weight}\\ \text{of hydrogen}\end{array}\right\}\ \text{unite with}\ \left\{\begin{array}{c}\text{16 parts by}\\ \text{weight of oxygen}\end{array}\right\}\ \begin{array}{c}\text{to form 18 parts by}\\ \text{weight of Water.}\end{array}$$

Nitrogen.—Occurrence: four-fifths the volume of air, exists combined in nitre, and forms part of animal and vegetable substances. Made by subtracting oxygen from air, and by heating certain of its compounds. Is a gas, without colour, taste, or smell. Does not support combustion, and will not burn. Unites with hydrogen, oxygen, aud other elements.

Carbon.—Occurrence: in all animal and vegetable substances. Exists in three forms, or allotropic modifications. (1) Diamond, (2) Graphite, (3) Charcoal. Each form unites with oxygen to produce carbon dioxide.

Carbon Dioxide—Exists in small proportion in air, and is respired by all animals. Also found at bottoms of old wells, in fermentation, and as *after-damp* in mines. Prepared by acting upon a carbonate, such as marble, with an acid. Is a heavy gas, possessing no colour or smell. Will not support combustion. Dissolves in water, and produces an acid solution. Can be easily compressed into a liquid and into a solid.

Acids.	*Bases.*
Always contain hydrogen. Generally have a sour taste, and turn blue litmus red.	Always contain a metal, and have the power of neutralising acids.

Salts.
Produced when the hydrogen of an acid has been replaced by a metal.

Iron.—Occurrence: almost entirely in combination with other elements, as in magnetic iron ore (black oxide of iron), hæmatite (red oxide of iron), clay ironstone (carbonate of iron), and iron pyrites (bi-sulphide of iron). Unites with oxygen in moist air, to form iron-rust. When heated, will burn in oxygen and form black oxide of iron. Also, when heated, will unite with the oxygen of steam to form black oxide of iron, and leave the hydrogen.

Mercury.—Occurrence: sometimes in the liquid form, but more commonly as cinnabar—a compound with sulphur. Heaviest liquid known, and with the exception of bromine the only element liquid at ordinary temperatures. When heated, unites with oxygen to form mercuric oxide. Dissolves many metals to form amalgams.

Silica.—Compound of silicon and oxygen. The most abundant binary compound in the earth's crust. Occurs in crystals as quartz and tridymite and amorphous as chalcedony, jasper, and opal. Prepared artificially, is a white, gritty powder, insoluble in water or acids.

Lime.—Exists combined with carbon dioxide in all carbonates. Formed by heating limestone (calcium carbonate) in a kiln. Two binary compounds are thus produced—lime (calcium oxide) and carbon dioxide, which goes off as gas. Forms a definite compound (calcium hydrate) when slaked with water. Gives a brilliant light when strongly heated.

Common Salt.—A binary compound of sodium and chlorine, and is the principal source of both these elements. Occurs as rock salt, also in brine springs, salt-lakes, and sea-water. Sometimes found in large colourless crystals.

Questions on Chapter IX.

(1) Name the elements of which water, common salt, and lime are composed, and state what you know about the elements in question. (1896.)

(2) (*a*) What is the most abundant oxide in the earth's crust, and of what elements is it composed?
(*b*) State what you know about the properties of this oxide.
(*c*) Name the crystalline form of this oxide.
(*d*) Name three rocks in which this oxide is found in its crystalline form. (1895.)

(3) (*a*) Name the chemical elements which are present in carbonate of lime (calcic carbonate).

(*b*) State the nature of each of these elements.
(*c*) How can carbonate of lime be broken up into two oxides? What are these oxides called?
(*d*) Name three common rocks which are composed of carbonate of lime. (1894.)

(4) State the composition of water :—
(*a*) By weight.
(*b*) By volume.
and describe how the composition of water may be demonstrated—
(*c*) By separating its elements.
(*d*) By uniting its elements. (1893.)

(5) (*a*) What is an oxide?
(*b*) Name two oxides which are always present in the atmosphere, and give their composition.
(*c*) What is the most abundant oxide in the crust of the globe?
(*d*) State what you know concerning the composition and mode of occurrence of this oxide. (1892.)

(6) What chemical element is present both in air and water? State the chief properties of this elementary substance. What proportion of this element is contained in air and water respectively? In what condition does the element exist in air and water respectively? (1891.)

(7) (*a*) Name the two elements which are present in the greatest abundance in the earth's crust.
(*b*) State what you know about the nature of these elements.
(*c*) In what condition do these elements exist in the earth's crust? (1890.)

(8) Give experiments showing how any two binary compounds can be formed. (1890.)

CHAPTER X

THE EARTH

Definition of an Angle.—Before we can proceed to a consideration of the earth's position in the universe, and of its movements with reference to the heavenly bodies, it is necessary to briefly refer to some geometrical definitions in terms of which such phenomena are described. We must add to our knowledge of the measurements of space. Up to this stage we have referred only to linear measures, and how with these area and volume can be estimated. We must first deal with angles. An angle has been defined by Euclid as *the inclination of two lines which meet together but are not in the same straight line.*

EXPT. 159.—Procure a pair of dividing compasses and hold one leg in a fixed position. Gradually move the other round, and notice that the inclination of the movable leg to the fixed one regularly increases, or the *angle between them becomes greater.* When the moving leg has been moved completely round it has described a *circle.*

Definition of Circle.—The preceding experiment brings us naturally to the definition of a circle, and again following Euclid we can speak of it as *a plane figure bounded by one line called the circumference, and is such that all lines drawn from the centre of the circle to the bounding line are equal.*

From Expt. 159 the student will at once perceive that the moving leg remains the same length during its revolution, and that its point marks out a continuous line which encloses a figure of the nature described in the above definition.

Definition of a Plane.—We have spoken of the circle as a "plane" figure, *i.e.*, one lying in the same plane. A plane is a surface, *e.g.*, the surface of the page on which this is printed is a plane surface. Such a *plane has length and breadth but no thickness, and is such that any two points being taken in it the straight line between them lies wholly in that plane.*

Unit of Angular Measurement.—The general plan adopted in measuring angles is to divide a circle into 360 equal parts, and to call each part a *degree* (1°). Thus in our last experiment the movable leg of the compasses has traced out an angle of one degree when it has gone round $\frac{1}{360}$ part of a complete revolution. When it has performed one-quarter of its journey round it has made an angle of ninety degrees, or a *right angle*, as it is called (Fig. 66).

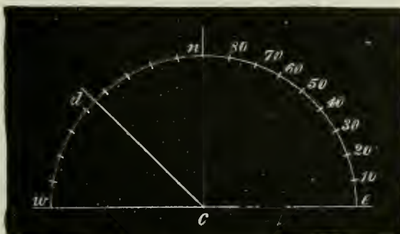

FIG. 66.—Angles. The angles *e c n* and *w c n* are Right Angles; that is, each is 90°. The angles *w c d* and *n c d* are each 45°.

The minute hand of a watch or clock moves through 360 degrees in an hour, or ninety degrees in every quarter of an hour, and this is true whatever the size of the timepiece. This reveals a very important fact, viz., that the size of an angle is quite independent of the length of the lines between which it is contained or the *arms* of the angle. This is well seen in Fig. 67, where a watch and a clock, the faces of which have the same centre, are shown, indicating precisely the same time of day or with the same angle between their hands. Evidently, then, all circles contain 360 degrees. All right angles contain ninety degrees, or there are four right angles to every circle. In accurate measurements parts of a degree are measured, and the subdivisions used are that one degree equals sixty minutes, and one minute ($1'$) equals sixty seconds ($60''$).

§ EXPT. 160.—Draw a large circle upon a sheet of cardboard, and divide it into 360 equal parts. Cut two narrow strips of card of a length slightly greater than the radius of the circle, and pin one end of each to the centre of the circle. Show, by placing the strips at

different inclinations to one another, the meaning of angular measurement, and the size of angles of, say, 30°, 60°, 90°, 120°, &c.

How to locate a Point on a Plane.—Co-ordinates.—Imagine it was necessary to exactly describe the position of one of the words on this page, how could it be done? One way would be to first count the number of lines from the bottom of

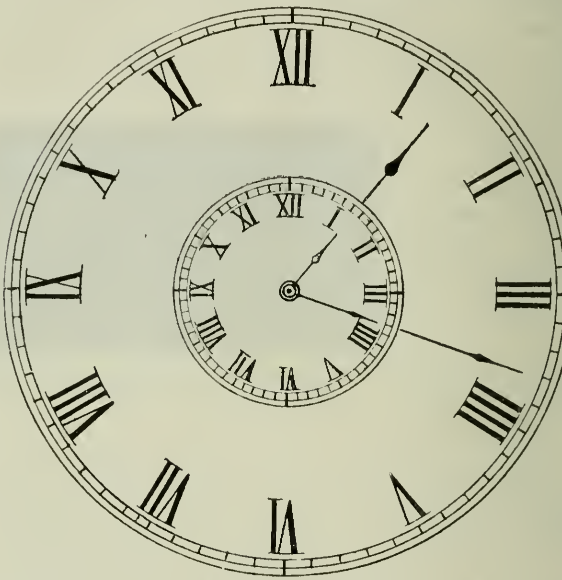

FIG. 67.—The Size of an Angle is independent of the length of the arms.

the page, which would give us the distance of the word from the bottom of the book. We should still be in doubt as to its precise position along the line so located, but if, in addition, we knew the distance of the word, say, from the left-hand edge of the page, it is quite clear that we should know exactly where the word was.

This method is known as *localisation by means of co-ordinates*, which we can say consists in finding the vertical and horizontal

distances from two fixed lines at right angles to one another. We shall learn more fully later that just such a plan is adopted to fix the position of places upon the earth's surface, the lines which correspond to the horizontal ones or the lines of print in the above illustration being called *parallels of latitude*, those corresponding to the vertical lines, *meridians of longitude*. Similarly, in the case of stars we locate their position at any given time by measuring their *altitude* and *azimuth*.

Altitude and Azimuth.—It has been seen that it is necessary to have two lines at right angles to one another from which to measure the co-ordinates of a point. In the case of stars, the horizontal line, from which the vertical height of a star or its altitude is measured, is the *horizon*. *The horizon is the line along which the sky and earth appear to meet.* It is most clearly defined at sea when there are no obstructions in the way.

The line from which the azimuth is measured is the line which joins the north and south points of the horizon.

Thus, then, when we have measured the altitude of a star, we know that it is on a line at a certain distance above the horizon, and when, in addition to this, we know its azimuth, we are aware that it is at a certain distance from the north and south line above mentioned, along the ascertained line. Where lines parallel to the horizon and the north and south line, at distances according to the altitude and azimuth respectively, cut one another, the star at the time of observation is situated.

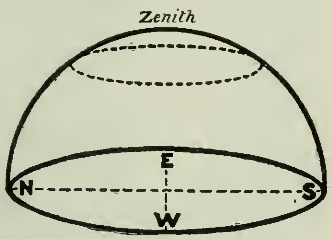

Fig. 68.—Altitude and Azimuth.

§ Expt. 161.—Place the divided sheet of card used in Expt. 160 upon a table, and mark upon it the four cardinal points. Arrange a large pair of dividing compasses upon the cardboard, so that the legs will open in a vertical plane while the angle between them is at the centre of the circle. Use this arrangement to illustrate the meaning of "altitude" and "azimuth," and that two such angular measures determine the position of a celestial object at any particular moment.

§ Expt. 162.—Explain the localisation of places upon the earth by means of latitude and longitude with the same arrangement.

Measurement of Altitude and Azimuth.—The student must clearly understand that altitude and azimuth are both measured in angles, for it is manifestly impossible to measure a

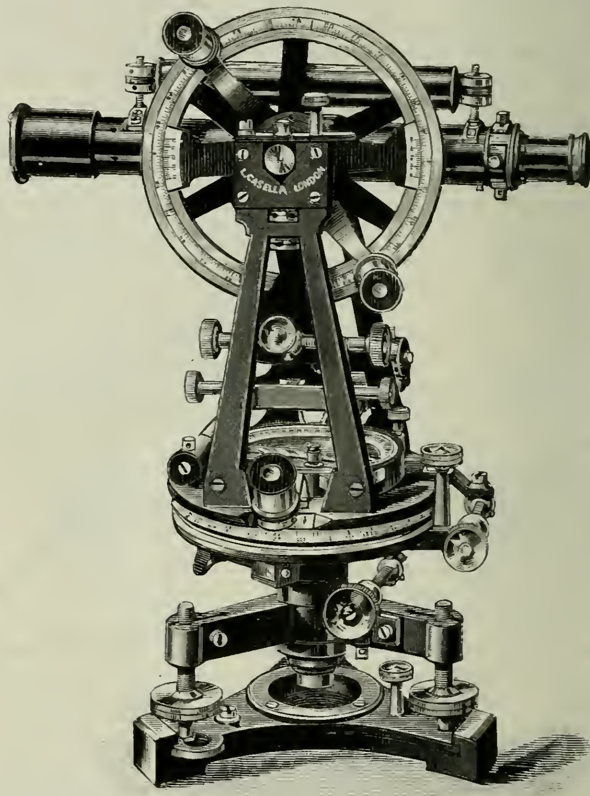

FIG. 69.—A Theodolite. [The type of instrument made by Louis P. Casella.]

length from the horizon to a star. The instrument used in measuring these angles is called the *theodolite*, the construction of which is shown in Fig. 69. The telescope can move in

a vertical plane round the vertical circle which is shown. The angle which the telescope makes with the horizontal can be read off in degrees, minutes, seconds, on the vertical graduated circle, and measures the altitude of the object which is being viewed by the telescope. The telescope being clamped, it is possible to move the framework supporting it round in a horizontal plane, and the angle through which it is thus moved measures the azimuth.

From what has been said it follows that in the case of bodies which are moving across the sky there is a constant change of altitude and azimuth, though, as will be seen, it is possible to have an alteration of azimuth without one of altitude.

Form of the Earth.—The history of the different ideas which men have had respecting the shape of the earth forms an interesting example of the change in attitude of man's mind towards all questions as his knowledge increases. In early times the most fanciful notions concerning the earth's form found ready acceptance, and even in recent times proofs of the globular shape of the earth were accepted which were really not proofs at all. At the present time we believe that the earth is more or less spherical, that is, more or less round like a ball, for reasons like the following :—

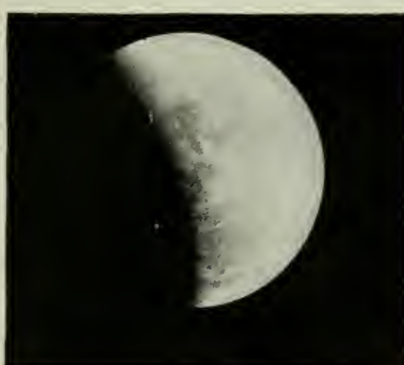

FIG. 70.—Photograph of an Eclipse of the Moon, showing the curved form of the earth's shadow.

1. *The shape of the earth's shadow cast upon the moon during lunar eclipses is always round.* We know from geometry that the only solid which always gives a round shadow wherever the light which throws it is situated is the *sphere.* Because the shape of the earth's shadow is always round, whatever may be its position with regard to the sun, we feel justified in asserting

that the earth must be a more or less perfect sphere. From other considerations, which will in due course be brought before the student's attention, we believe that the sphere is not perfect, but flattened towards two points as much removed from one another as they can be.

§ EXPT. 163.—Project, by means of a candle at the distance of, say, some ten feet from a white screen, the shadow of a ball. The shadow is always round, whatever way the ball is turned.

2. *The dip of the horizon is every where the same. In consequence it appears circular to an observer raised above the earth's surface.*

It is characteristic of a sphere that, from whatever point it is viewed, it always appears circular, and it will be evident that

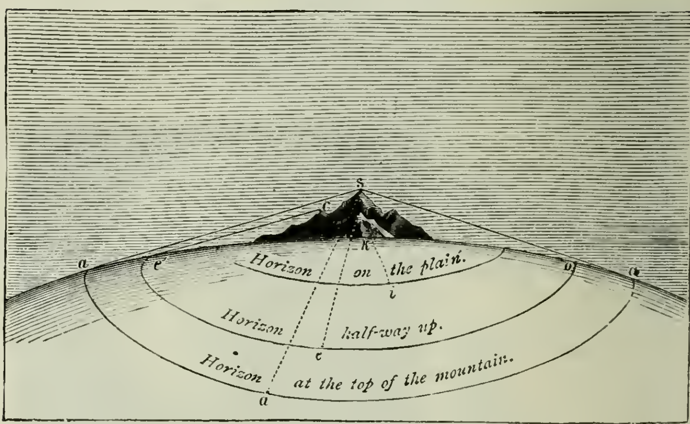

FIG. 71.—The Horizon is always Circular.

since the horizon bounds a circular space at whatever altitude the observer is situated, and wherever he may chance to be upon the earth's surface, that this reason alone gives us strong grounds for asserting that our planet is globular.

3. *The times of rising, southing, and setting of the sun and stars is different at places situated on different meridians.* If the earth were flat, as soon as the sun appeared above its edge,

he would be visible throughout the earth's surface. But this is by no means the case. Similarly, the sun would attain its highest position in the sky at an instant which would be the same for all parts of the flat earth. This, too, is just as far from the truth as the first conclusion arrived at on our supposition. When it is noon at Greenwich the sun is rising to the people of St. Louis and setting to those of Calcutta. This reason should be reverted to after the section on longitude and time has been read.

4. *The altitude of the pole-star regularly increases as the observer travels from the equator to the poles. Some stars disappear while others continually appear as he travels polewards.* If the surface of the earth were horizontal the altitude of any star would be the same from whatever place on the plane it was viewed. But observation shows beyond a doubt that as we travel northwards the altitude of the pole-star, for example, gets greater and greater until at the north pole it would be exactly overhead, or its altitude would be 90°. If we travel in the reverse direction, the reverse changes occur, the altitude diminishes from 90° until at the equator it appears on the horizon, or its altitude is 0°.

To bring about these changes in the altitude of the pole-star, it is manifest that the observer must have described an angle of 90°, for the change in the observer's position could have no actual effect upon that of the pole-star. Hence in travelling from the pole to the equator the observer describes one-quarter of the distance round the earth, and if he goes right round he would cover $4 \times 90°$, or a complete circle.

Measurement of the Earth's Circumference.—We have satisfied ourselves that the earth is spherical in form, and it will be desirable now to consider how the length of a line round the earth has been determined. A line encircling the earth and passing round it in such a way that the plane containing it passes through the centre is called a *circumference* of the sphere. We can ascertain its length from the following considerations.

From what has been said in the last of the above reasons for believing the earth to be spherical, we know that to make a difference of one degree in the altitude of the pole-star, we must travel through an angle of one degree measured along the circumference of the earth. In order that such a circle round the earth may fulfil the condition which has just been given, we must travel along a meridian as we move polewards. The plan to be adopted, therefore, is *to travel northwards or*

southwards for such a distance along a meridian that we cause a difference of one degree in the altitude of the pole-star. When we have done this we have completed $\frac{1}{360}$th part of the circle round the earth (*see* p. 145), and consequently all we have to do to determine the circumference is to multiply the distance obtained by 360. It has been found that the distance to be travelled to bring about such an alteration of one degree in the pole-star's altitude is not always the same. As the poles are approached the distance becomes greater. We have seen that no difference in altitude would be produced on a flat earth, and we can argue that since for a given journey the difference in altitude produced is less towards the poles we must be travelling on a flatter earth, *i.e.*, the earth is flattened somewhat near the poles. These varying lengths are measurements of degrees of latitude along meridians.

Length of the Circumference.—In travelling from the equator to the poles, then, there is a gradual increase in the length of a degree of latitude. The amount of such difference will be seen from the following table :—

Latitude	Distance travelled to bring about difference of 1° in altitude of pole-star = length of 1° of Latitude.
Equator	68·69 miles
10°	68·70 ,,
20°	68·77 ,,
40°	69·00 ,,
60°	69·21 ,,
80°	69·38 ,,
Pole	69·39 ,,

If we take an average value of the lengths of these degrees of latitude, say 69 miles, and multiply it by 360, we obtain 24,840 miles as the length of 360 degrees, or a complete circle round the earth ; and if this is divided by $3\frac{1}{7}$ (the ratio of the circumference of a circle to the diameter) the diameter is found to be 7,918 miles.

Exact Shape of the Earth.—A globular body flattened towards two points, situated as far away as possible from one another, is called an *oblate-spheroid*. These points of flattening are called the *poles*, and the line joining the poles is known as the *axis*. If the degrees of latitude were all of exactly the same value the earth would be a perfect sphere.

Reason for the Flattening at the Poles.—

EXPT. 164.—Procure a circular hoop of thin steel, and support it upon an axis attached to a whirling table, as shown in Fig. 72. Set it

spinning by turning the handle of the whirling table. Notice that the hoop assumes a more flattened form. The flattening is increased as the rate of spinning is made greater.

EXPT. 165.—Add a few drops of oil to a liquid in which they just float, as in Expt. 14. By means of a glass rod set the liquid spinning,

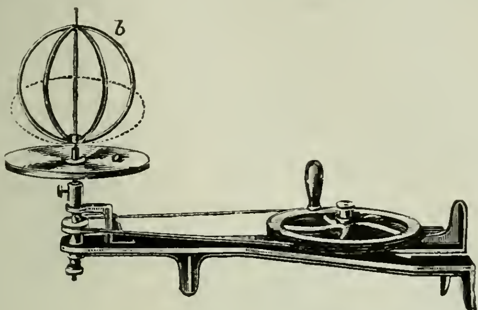

FIG. 72.—Apparatus to show the flattening produced by spinning a flexible steel hoop.

and notice that the drop, which was at first perfectly globular, takes the same flattened form when it is made to rotate.

§ EXPT. 166.—Fasten a knitting needle with wax to the lowest point of a watch glass. Moisten the glass with soap solution. Slip the needle into a vertical hole in the central peg of a top when it is spinning at a moderate rate. Blow a soap bubble on the watch glass and draw attention to the fact that it is flattened.

These experiments enable us to account for the shape of the earth. If we could be sure that the earth was spinning, and that the material of which it is made was at any time sufficiently fluid to be moulded like the drop in Expt. 165, we should clearly be able to say that its shape was the natural result of such rotation. There can be no doubt that the earth is so spinning, and the reasons for the assertion are given later on in this chapter. We are equally sure, also, that this planet was once in a fluid state. As the student will learn more fully in another place, many of the rocks of which the earth is built provide indisputable proof of a previous liquid condition. Moreover, the materials emitted from volcanoes during eruptions are given out as liquids. When we have studied what is known of the sun's nature we can judge by analogy what was probably the original state of the earth. These and other reasons leave no room for

doubt that the earth has taken its present shape in obedience to the rules regulating the behaviour of spinning bodies which are free to move.

Density of the Earth.—We have already learnt that the density of a body is generally spoken of in terms of the density of water. The comparison of the weight of a given volume of a substance with the weight of an equal volume of water gives us a number called the specific gravity. The number thus obtained in the case of the earth is 5·6. This means that the earth is about five-and-a-half times as heavy as it would be if it were entirely composed of water. The average density of the materials making up the outside shell of the earth, which geologists can get at and study, and called the *crust of the earth*, is only 2·75. The student will therefore understand that to bring the density of the earth as a whole up to 5·6, there must be much heavier material somewhere nearer the centre. It has been estimated that the density of the materials near the centre of the earth must be as much as 9 or 10.

How the Density has been determined.—It would take us too far to describe fully the various plans which have been adopted to determine the earth's density. We can only name the methods which Prof. Lockyer gives in his admirable *Lessons in Astronomy*:—

(1.) By comparing the attractive force of a large ball of metal with that of the earth.

(2.) By determining the degree by which a large mountain will deflect, or pull out of the upright towards it, a plumb-line.

(3.) By determining the rate of vibration of the same pendulum—

(*a.*) On the top and at the bottom of a mountain.

(*b.*) At the bottom of a mine, and at the earth's surface.

The Cavendish Experiment.—The determination by the first of the above methods was made by Cavendish in 1798. As we have seen (p. 34), the weight of any body is the measure of its attraction by the earth. The law of gravitation tells us that, not only the earth, but all other large bodies also attract smaller ones to them. Cavendish arranged two small balls of lead at the ends of a thin wooden rod about six feet long, and then suspended the rod by a fine wire attached to its centre. Two large leaden spheres, one on either side of the small ones, were brought

up to the rod when it was perfectly at rest. The large leaden spheres attracted the small balls (*see* p. 33), and Cavendish accurately measured the deviation. It was easy to calculate, then, what the deviation would have been had the leaden spheres been as large as the earth. But the attraction of the earth for the small balls is known, for it is their weight. Hence he had the proportion :—

$$\text{The density of the earth} : \text{The density of lead} = \text{Weight of the ball} : \text{Attraction of a sphere of lead as large as the earth for the ball.}$$

This ratio gives the mean density of the earth to be 5·45 as great as water. The average density of the rocks which make up the earth's crust is, however, only about 2·75 times the density of water.

TERMS USED IN DESCRIBING THE EARTH.

EXPT. 167.—Procure an orange which is somewhat flattened in the direction of the scar where the stem was attached, and push a knitting needle from one place of flattening to the other, that is, in the line of its shortest diameter. Spin the orange round upon the needle. While the orange still spins imagine the needle to gradually become thinner, until finally it disappears. The line which you can think of as taking the place of the needle is the *axis* of the spinning orange. But this line is the shortest diameter, or the axis and shortest diameter coincide (*see* Fig. 73).

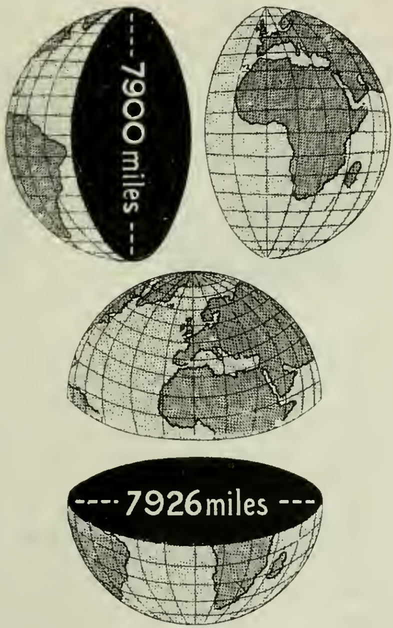

FIG. 73.—Polar and Equatorial Diameters of the Earth. From Gregory's Physiography Diagrams (Chapman and Hall).

Instead of the orange in the experiment, think of the earth. Its shortest diameter is its *axis*, and is the line on which it spins or rotates. The ends of the axis are called *poles*, which we have already spoken of as the points of flattening. An imaginary circle round the earth midway between the poles is called the equator. Circles parallel to the *equator*, which will be smaller as the poles are approached, are called *parallels of latitude*. The equator is the longest parallel of latitude, and it is called 0°. The parallel of latitude through the pole is called 90°, evidently it will be a circle which has become so small that it is only a point. The equator is sometimes called a *great circle*, while the other parallels of latitude are

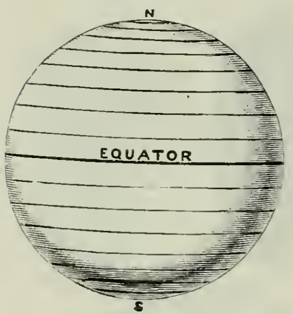

FIG. 74.—Parallels of Latitude.

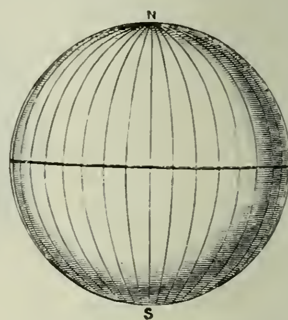

FIG. 75.—Meridians of Longitude.

called *small circles*. If we know the parallel of latitude on which a place is situated, we know how much it is north or south of the equator, but before we can locate it we must know where upon the parallel of latitude the place is, and to do this we make use of *lines of longitude*.

Lines of longitude form circles which pass through both the North and South Poles and consequently all have the centre of the earth for their centre, that is they are all *great circles*. There is no one of these from which all people measure as a matter of course, and consequently measurements of longitude start differently in different countries. In this country and for British people generally, the line of longitude which is taken as the starting point is the one which passes through the vertical

cross-wire of the transit instrument at the Greenwich Observatory. This is called 0°, and those on the east and west of this one are referred to as being so many degrees east or west longitude. The numbering is continued until 180 is reached, and the student should have no difficulty in understanding that we can speak of the line of longitude marked 180° neither as east nor west longitude, since we mean the same line whichever we say. These lines of longitude with a different number attached are, then, semicircles, the two marked respectively as 0° and 180° together forming a great circle. A comparison of Figures 74 and 75 shows that whereas the lines of latitude are always the same distance apart, those of longitude get closer and closer together as the poles are approached.

§ EXPT. 168.—Paint an orange white, and place a knitting needle through it as already described. Draw on it parallels of latitude and meridians of longitude. Place the eye at a distance from the orange, and observe each meridian of longitude as it passes when the knitting needle is vertical. Incline the knitting needle at $23\frac{1}{2}°$ with the vertical away from the eye, and repeat the observations.

Rotation of the Earth on its Axis.—The earth spins round on its axis in a manner which exactly resembles the spinning orange in Experiment 167. This spinning motion constitutes *rotation.* In the case of the orange rotating upon the needle as an axis, it is quite apparent that the axis itself is free from any spinning motion, while the parts of the orange farthest away from the needle move through the greatest distance in a given time or have the highest velocity. Similarly with the earth, the poles are at rest, while places on the equator are carried through a distance of about 25,000 miles in the time of one rotation, which is twenty-four hours, that is they have a velocity of over 1,000 miles an hour.

Apparent Motions of Stars around the Celestial Poles.—If the northern sky be watched on a fine night all the stars will be seen to turn as if they were fixed on a solid vault pivoted at a point near the north star, or pole-star. A striking way to show this is afforded by photography.

§ EXPT. 169.—Point a lens and camera, containing a sensitive plate, to the pole-star, and expose it for a couple of hours. Then take out the plate and develop it.

While the camera is directed towards the sky the stars apparently move around the north celestial pole, the result being that they all leave trails upon the photographic plate. The pole-star will trace an arc of a very small circle (thus proving that it is not situated absolutely at the pole), while the other trails will be arcs of much larger circles. A similar result is obtained if a photograph is taken of the region around the south celestial pole by a photographer in the southern hemisphere. This indicates that the earth is in rotation, the north and south celestial poles being the points above the ends of the axis of rotation.

CHIEF POINTS OF CHAPTER X.

Measurement of Angles.—One degree (1°) is $\frac{1}{90}$ of a right angle and $\frac{1}{360}$ of a circle.

60 seconds of arc (60″)	=	1 minute of arc (1′).
60 minutes of arc (60′)	=	1 degree (1°).
90 degrees	=	1 right angle.
4 right angles	=	a complete revolution.

Altitude signifies angular distance above the horizon, measured in a vertical plane.

Azimuth is angular distance from the true north or south point, measured in a horizontal plane.

Latitude is shortest angular distance north or south of the equator. Parallels of latitude are circles round the earth parallel to the equator.

Longitude is shortest angular distance east or west of a selected meridian.

Indications that the Earth is Globular.—(1) The shape of the earth's shadow, cast upon the moon during lunar eclipses, is always round. (2) The dip of the horizon is everywhere the same, and consequently the complete horizon appears to be circular. (3) Stars rise, south, and set at different times at places situated on different meridians. (4) The altitude of the pole-star is equal to the latitude of the place of observation.

Determination of the Dimensions of the Earth.—Find distance necessary to travel in order to cause 1° difference in altitude of pole-star. The result is the length (69 miles) of 1° of latitude, and this length × 360 gives the length of earth's circumference.

Diameter = circumference ÷ $3\frac{1}{7}$ = 7,918 miles.

The Exact Form of the Earth is that of an oblate-spheroid. This is indicated by (1) Degrees of latitude increase in length polewards; (2) a plastic mass, as the earth once was, becomes compressed at the poles by rotation: (3) the attraction of gravity is greater in polar than in equatorial regions.

Density of the Earth.—Average density of materials of earth's crust, 2·75. Density of earth as a whole, 5·6.

Questions on Chapter X

(1) What is the system of angular measurement? Draw as nearly as you can, by estimation, angles of 30°, 45°, 60°, 90°.

(2) Define horizon, altitude, azimuth.

(3) Give as many reasons as you can for the belief that the earth is globular in form.

(4) How could you determine roughly the earth's dimensions?

(5) Explain the Cavendish experiment to determine the mean density of the earth.

(6) Describe the apparent motions of the stars as seen when facing north in England on a fine night.

(7) How would you explain to a class the meaning of latitude and longitude?

(8) What reasons are there for believing that the earth is flattened at the poles?

CHAPTER XI

ROTATION OF THE EARTH AND MEASUREMENT OF TIME

The Rotation of the Earth causes Day and Night. —The sun and the earth are bodies in space; the former is luminous, while the latter is a dark body with no light of its own. The sun sheds his light in every direction, and lights up that half of the earth which is nearest to it, the remote half meanwhile being quite in the dark (*see* Fig. 78). Were the earth at rest this would be the permanent condition of things, one half would always be illuminated or enjoy the brightness of day, the other would be in the perpetual darkness of night. But since the earth is rotating, new parts of our planet are being continually brought "out of darkness into light." The night is regularly followed by the day, and as the spinning carries the place round, it is in due course taken out of the sunshine into the shadow of evening again. In the next chapter the student will learn how it is that the days throughout the year are of varying lengths.

Proof of the Earth's Rotation.—The apparent daily motions of the sun and stars are a direct consequence of the earth's rotation, but a moment's thought is enough to convince us that exactly the same appearances would be observed were the earth, as was originally thought, the rigid centre of a moving universe. If we think of the earth in this way as fixed, while the heavens move round it as a centre once in twenty-four hours, we should have just the same alternation of day and night, and the identical succession of rising, southing and setting of the celestial bodies such as has been remarked. True,

the movements of the spots on the sun across his disc afford evidence of a rotation of that luminary, and, judging from analogy, we should have a strong supposition for the earth's rotation. But, fortunately, direct proofs are to hand.

We can summarise the experimental proofs of the earth's rotation :—

1. By the observation of bodies falling from a great height towards the earth. Such falling bodies are deviated towards the east.

2. By experiments with Foucault's pendulum.

3. By experiments with Foucault's gyroscope.

We shall only be able to fully describe the second of these proofs.

Foucault's Pendulum.—Newton's first law of motion (p. 30) asserts that all matter possesses inertia. Foucault made use of the possession of this property by a heavy pendulum to demonstrate the earth's rotation. If such a pendulum be set oscillating it resists any attempt to force it out of the plane in which it is swinging. The

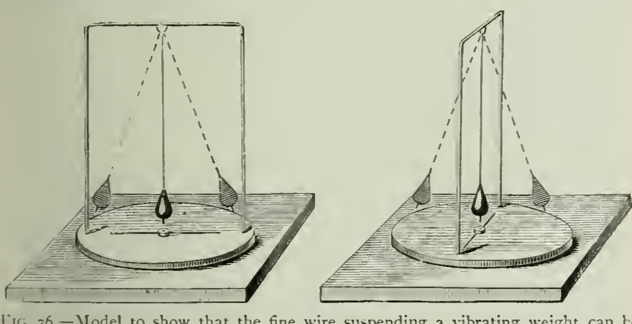

FIG. 76.—Model to show that the fine wire suspending a vibrating weight can be twisted without exchanging the direction of vibration.

device shown in Fig. 76, due to Mr. R. A. Gregory, and described in his *Planet Earth*, shows this very prettily.

§ EXPT. 170.—Swing a heavy ball suspended freely by a wire from a point fixed to a support which rests on a board that can be moved round as required. Let a hog bristle just touch the board, and on the board place a smooth piece of paper covered with lamp-black. Cause the pendulum to swing, by moving it to an angle with the vertical by a piece of thread and then cutting the thread with scissors. Slowly rotate the board round a centre. It will be found that the ball swings

in the same direction as regards the room as that in which it originally started, and regardless of the motion of the board.

Making use of this fact, Foucault suspended a heavy iron ball, by means of a long thin wire, from the roof of the Panthéon in Paris. The pendulum thus formed was pulled out of the perpendicular and held on one side by a thread which was attached to the wall. Foucault caused the pendulum to swing to and fro over a circle of sand on the floor of the Panthéon, but the experiment can be as satisfactorily done if a table on which marks have been drawn be substituted.

The pendulum is set swinging by burning the thread. As time goes on the suspended weight seems to pass along a different line on the table from that originally traversed, and it is clear that one of two things must have happened—either the plane of the pendulum's oscillation must have altered, or else the table must have turned round. But the experiment we have described shows that the former alternative is an impossible one, and we are forced to the conclusion that the table, and therefore the earth of which it is a part, gradually turns round. If this experiment were performed at either of the poles the table would turn completely round once in twenty-four hours.

Apparent Movements of the Stars due to the Earth's Rotation.—We have already called attention to the difference in altitude of the pole-star, which is observed as we travel from the equator to the poles. We must now consider somewhat more fully the changes which are noticed in the apparent movement of the stars as we move either from the equator to the poles or in a contrary direction. A careful examination of Fig. 77 makes the matter quite clear. Let us take the three positions of the observer, which are there depicted in order.

1. When the observer is at either of the poles, say the north, the pole-star appears exactly overhead; indeed, it is so named because if the earth's axis were continued to meet the heavens it would pass almost exactly through this star. The horizon is contained by the plane passing through the earth's equator, that is, the *celestial equator* and the horizon coincide. All stars appear to move round the observer in circles, and remain visible throughout their diurnal journey. Or we may say their apparent paths are always parallel to the horizon.

2. When the observer is at the equator the pole-star appears on the horizon, and all stars seem to describe semicircles in the heavens. The planes containing the paths of the stars are all vertical, and consequently stars on the celestial equator, when in their highest positions, will be exactly in the zenith.

3. When the observer is in *middle* latitudes, say at London,

the stars seem to belong to three classes. (i) Those which can be seen throughout the whole of their apparent journey, *i.e.*, which never set; (ii) those which are visible only for a part of their apparent path, *i.e.*, which both rise and set; (iii) those

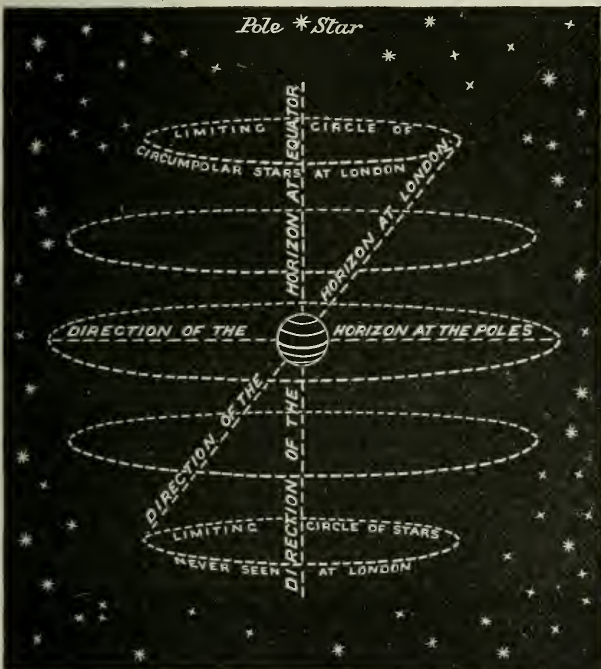

FIG. 77.—To explain why the altitude of the Pole-Star varies with latitude, and also to illustrate the apparent paths described by stars when viewed at the poles, at London, and at the equator.

which never come into sight at any period of their apparent diurnal motion, *i.e.*, which never rise.

Apparent Daily Motion of the Sun.—We will consider the case of the sun more fully. It appears to regularly go

through certain periodic changes of position. It rises, travels higher and higher into the sky, reaches its highest position, sinks lower and lower, and finally sets.

If a pole be erected with a horizontal plane round its base on which the length of the shadow cast by the sun may be received, it will be found that from sunrise onwards the shadow of the pole regularly diminishes in length as the sun rises higher, and that at noon the length of the shadow is shortest. From this moment until sunset the shadow increases in length. The line passing through the shortest shadow is known as the meridian of the place, and if continued in both directions it will pass through the north and south poles. This observation, therefore, affords a means of ascertaining the true north and south line from which angles of azimuth are estimated.

Sundials. — This regular change which the length of a shadow undergoes provides a ready means of measuring time. When the sun rises in the east he will throw a shadow of the pole in the last experiment to the west, and as our luminary travels towards the south the shadow will move northwards until, when the sun is due south or at his highest altitude, and is, as we have seen, passing over the meridian of the place, the shadow will point due north. This is called *southing*. The westward journey of the sun throughout the later half of the day will be accompanied by a corresponding eastward motion of the shadow. The interval of time between the sun's highest position on any one day to its corresponding position on the next succeeding day is an apparent *solar day*. These apparent solar days will vary in length throughout the year for reasons which will be more fully apparent as we proceed.

§ EXPT. 171.—Fasten a small rod at right angles to a flat board. Place the board flat on a table so that the rod is vertical. Move a candle in a semicircle above the table, and note the change in the angle that the shadow of the rod makes.

In constructing a sundial to properly measure time in the manner described, we substitute for the pole mentioned above a projecting rod, which is called a *style*, and is arranged in such a way that it is parallel to the axis of the earth, which condition of things obtains when the rod points to the pole-star, a fact the student will appreciate better when we have proceeded a little further. The shadow is received upon a plate, which is called the *dial*. The dial is marked in the following manner :—The direction of the shortest shadow, the line, that is, pointing

due north, is marked XII, for when the shadow falls upon this division it is noon. Since the sun appears to complete a circle round the earth in a day of twenty-four hours, it is evident that the shadow will describe an angle of 360 divided by 24 degrees in an hour, and consequently lines drawn making angles of 15° to the west and east of the line of shortest shadow will be marked XI and I respectively.

But the altitude of the pole-star varies directly with the latitude, and in consequence the direction of the style must also depend upon the same fact. It will be seen, as we proceed, that the altitude of the pole-star measures the latitude of a place, and we thus obtain the rule *for horizontal dials that the inclination of the style must equal the altitude of the pole-star or the latitude of a place.*

In the case of vertical dials the style is fixed at an angle which is the difference between 90° and the latitude of the place.

Apparent Daily Motion of a Star.—Just as in the case of the sun so we have seen with all the stars, they rise, *south*, and set. But whereas with the sun the interval between two successive southings varies throughout the year, it is found that the time which elapses between two succeeding southings of a star at any season of the year is always the same. This interval constitutes *a star* or *sidereal day*. If, then, we can find some means of ascertaining the exact moment at which a star souths or passes over the meridian of a place, we have a method of measuring time in terms of an interval of time which is always the same.

The Transit Instrument affords us such a means. It consists of an astronomical telescope (p. 99), which is firmly fixed between two vertical uprights and supported so that it can move round in a vertical plane. The eye-piece of the telescope is provided with cross-wires, one vertical and the other horizontal. When the telescope is moved round, the vertical cross-wire traces out a line which passes through a point exactly overhead, called the *zenith*, and also, for the instrument is so fixed, through the north and south points on the horizon. The line thus traced out is, of course, the meridian. When, therefore, the image of a star crosses the vertical cross-wire of such an instrument, or *transits*, as it is called, we have the exact second of the star's southing. The interval between such an observation and a similar one with the same star the next night is an exact sidereal day.

Greenwich and Local Times.—An incidental reference to the difference between Greenwich time and that of places to

the east and west of this locality was made in the last chapter. Being able, however, to now regard the earth as a spinning globe, we are in a position to explain this difference more fully. Fig. 78 makes the matter very simple. The student must suppose himself in space looking down upon the north pole of the earth, which is situated at the intersection of the diameters of the circle representing the equator of the earth. The circle is divided into twenty-four equal parts, and hence the angle between any pair of radii will be 360 divided by 24, or 15 degrees.

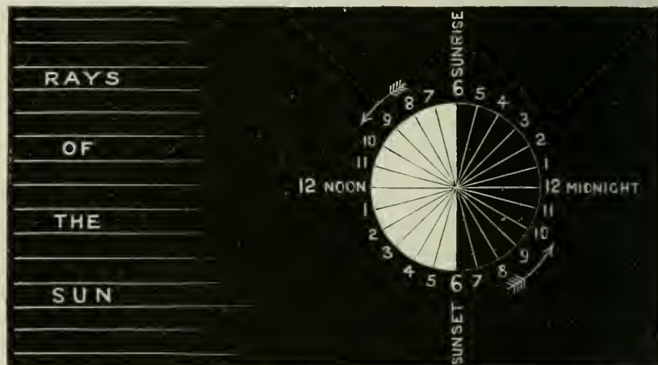

Fig. 78.—To explain the different times at places east and west of Greenwich.

As the globe spins round each radius in turn occupies the position of that one marked "12 noon." An observer in this position will see the sun in his highest position for the day, or on the meridian, that is, southing. The observer situated at the opposite end of the same diameter will be as far away from the sun as he can possibly be. Or, to take an example, at places longitude 180° it will be twelve o'clock midnight when it is twelve o'clock noon at Greenwich. When the sun is on the meridian at Greenwich at places 90° W. and 90° E. it will be six o'clock in the morning and six o'clock in the evening respectively.

Again, when it is twelve o'clock noon at Greenwich, at

places 15° W. longitude it will be 11 a.m., while at places 15° E. longitude the sun has passed the meridian an hour ago, or it is 1 p.m.

Hence we get a rule for knowing Greenwich time at a place when we are aware of the local time and the longitude of that place. If we are west of Greenwich we add to the local time one hour for every 15° of longitude or four minutes for every degree ; while, if we are to the east we subtract the same amount. Similarly, if we already have Greenwich time, and we wish to know the local time we can, being aware of the longitude, subtract the same amount for places west of Greenwich and add it for places of east longitude.

But these facts are most useful in enabling navigators to determine their longitude. We have seen that clocks keep mean solar time. If, then, the mariner has with him an accurate chronometer keeping Greenwich time, that is, which records twelve o'clock when the sun is on the meridian of Greenwich, he can by noting the time of southing of the sun, which happens at twelve o'clock noon local time, tell the difference between local and Greenwich time. If the local time is slow compared with Greenwich time his longitude is west, and equal to a number of degrees obtained by reckoning 1° for every four minutes it is slow. If the local time is fast he is in east longitude, and on the meridian which is found by dividing the amount he is fast in the same way.

Mean Solar Day.—Equation of Time.—The student has learnt that the length of days measured by the sundial varies in length throughout the year, and will have no difficulty in understanding that no single one of these days will do for a convenient standard of time. But if the lengths of all the days in the year are added together, or the length of a year measured by the sun be divided by the number of days in the year, we obtain an interval of time which is always the same. Such a day, which is of course an imaginary one, is called a *mean solar day*. Sometimes the mean solar day will be longer than the day measured by the sundial, sometimes it will be shorter, and occasionally both days will be of exactly the same length. Sundial time is known as *apparent time*, and clock time as *mean time*. The amount which must be subtracted from, or added to, the length of the day measured by the sundial, in order to make

it equal to that of the mean solar day, is called the *equation of time.* Its value for every day in the year is given in the *Nautical Almanac.* All clocks and watches keep mean solar time, and consequently there is a difference between the time recorded by the sundial and that given by a correct clock equal in amount to the equation of time.

Comparison of Different Days.—It will be well for the student to carefully compare the various sorts of days together to see in what respects they resemble one another and in what they differ.

A solar day is the interval of time between the southing of the sun on any one day and the next recurrence of the same phenomenon. It is a day of variable length.

A mean solar day is a day of the average length of all the solar days in a year. It differs from the solar day by an amount of time called the equation of time.

A sidereal day represents the time which elapses between two successive southings of the same star. It is always of the same length.

Subdivisions of the Day.—The day is divided up into smaller equal amounts as follows :—

1 day	is subdivided	into	24 hours.
1 hour	„	„	60 minutes.
1 minute	„	„	60 seconds.

In naming the hours of the day the time of southing of the imaginary sun, or the mean sun, is called twelve o'clock noon, and the succeeding hours after this are called one, two, three, four o'clock, &c., until twelve o'clock midnight is reached, when the numbering is restarted. The corresponding hours are distinguished by adding the letters *a.m.* or *p.m.*, the former if the hour is before (*ante*) the passing of the meridian, the latter if the hour is after (*post*) the passage.

Astronomers, however, are in the habit of numbering straight on from the moment of transit of the mean sun, in the case of astronomical mean time. The old day is completed and the new day is started at the instant of southing, and the hours are numbered from 1 to 24, *i.e.*, instead of calling the hour next after midnight 1 o'clock a.m., astronomers would say 13 hours. *Sidereal time* is reckoned from 0 to 24 hours in a similar way, but the starting point is a particular point in the heavens, known as the vernal equinox.

Instruments for Measuring Time.—We need only concern ourselves with the modern contrivances for measuring time, viz., clocks and watches. It will be sufficient to regard these as instruments for measuring intervals of time in terms of the mean solar day to which attention has been directed. In a clock the rate is regulated by means of the pendulum, the properties of which can be best understood by an experiment.

EXPT. 172.—Attach a weight to the end of a cord. Fix the cord in such a way that the pendulum can oscillate freely. Set it oscillating, and notice how long it takes for the pendulum to complete a given number, say twelve, swings. Keeping the cord exactly the same length, attach a heavier weight and repeat the experiment. The time of swing remains unaltered. Keeping any one weight, observe the time taken to complete twelve swings when the length of the cord is varied. It will be seen that the time of swing varies with the length of the cord. Notice also that it does not matter if the pendulum makes a wide oscillation or a very small one, the time taken is the same.

If it were possible for the student to perform the experiment, it would be found that the time taken for the pendulum to swing backwards and forwards varies as it is taken from the equator to the poles, a fact that he will understand by referring back to p. 152. Or, putting the same fact in another way, in order that a pendulum may swing backwards and forwards in the same interval of time, it is necessary to alter the length of the cord in our experiment as we travel from the equator towards either pole. A pendulum of such a length that the distance from the point of suspension to the centre of the bob is 39·139 inches, swinging at Greenwich, completes one swing in a second of time. In a clock we have a mechanical contrivance for maintaining the swinging of a pendulum. We must content ourselves with referring the reader to books on astronomy and horology for an account of the construction of a clock. In watches the place of the pendulum is taken by a carefully suspended balance wheel.

Lengths of Different Days.—

	hours.	min.	sec.
Sidereal or Star Day	23	56	4
Mean Solar Day or Clock Day . .	24	0	0
Solar Day varies from	23	45	0
		to	
	24	16	0

Solar Day is exactly 24 hours mean time on April 15, June 15, August 31, December 24.

The Year.—Sidereal Year.—If the stars could be seen during the day (but because of the glare of the sun's light they cannot) it would sometimes happen that the sun would be in the same direction in the sky as one of the stars. When this was the state of things we should say that the sun and the star were in *conjunction.* If we made a note of the day and time of day at which this happened, we should notice that, as the days passed, the sun appeared more and more to the east of the star. As time went on the sun would appear to the west of the star, and eventually a second conjunction of the sun with the same star would occur. We call the time which elapses between one such conjunction and the next a *sidereal year*, which we can therefore define as *the length of time between one conjunction of the sun with a given fixed star and the next such conjunction.* The length of the sidereal year is 365 days 6 hours 9 minutes and 9 seconds.

The Tropical Year.—In considering the length of the day the student's attention was called to the variation

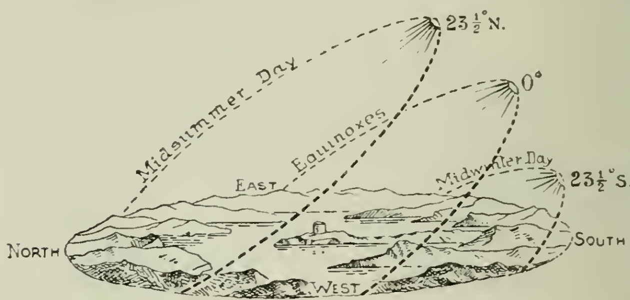

FIG. 79.—The apparent paths described by the Sun at different times of the year.

in length of the shadow of a pole cast by the sun at different times of the day. It was seen that there is a gradual diminution in such length from sunrise to noon and a corresponding increase from noon to sunset. If the length of the shadow at apparent noon be marked it will be found that this length varies from day to day. It is shortest on Midsummer Day, and gradually increases day by day until Midwinter Day

when it is longest. From this day onwards the shadow again decreases until the following Midsummer Day. On two days between the occasions on which the shadow is shortest the sun rises due east and sets exactly in the west, and the hours of daylight exactly equal the hours of darkness. These times on which the days and nights are exactly equal in length are called the *equinoxes*, and then the sun's position in the sky is just intermediate between that on Midsummer Day and Midwinter Day. This happens in the spring and again in the autumn. The first occasion constitutes the *vernal* or *spring equinox*, and the latter the *autumnal equinox*.

The interval of time between one spring or autumn equinox and the next succeeding one is called a tropical or equinoctial year. Its length is 365 *days* 5 *hours* 48 *minutes* 46 *seconds.* If the vernal equinoxes always occurred at the same time on the same day there would be no difference in the length of a sidereal year and a tropical year, but such is not the case, the reason for which we shall defer for the present.

The Civil Year.—The civil year should be of the same length as the tropical year. The seasons are regulated by the sun's apparent movements, and clearly it is desirable that these two periods should agree. As every one knows, the ordinary year in common life is made up of twelve months, which together share 365 days. But the tropical year is roughly $365\frac{1}{4}$ days long, and evidently in four years there is an accumulation of four quarter-days for which the civil year has not accounted. It is for this reason that every fourth year is made to have 366 days, and is called a *Leap Year.* By this expedient the average length of four succeeding years is made equal to $365\frac{1}{4}$ days, which is the approximate value of the tropical year. This correction is, however, a little too large ; for the tropical year is really 365 days 6 hours 48 minutes 46 seconds, whereas so far as we have gone the length of the average civil year is 365 days 6 hours. The correction is thus in excess by 11 minutes 14 seconds in a year, which is just about three days in 400 years, and to meet it, it is arranged that the leap years shall be as before, except that the century years shall only be leap years when they are divisible by 400, so that three leap years are omitted in 400 years. This brings the average length of the civil year into almost exact agreement with that of the

tropical year. A still more exact correspondence between the civil year and the tropical year is obtained by omitting a leap-year in every 128 years.

Chief Points of Chapter XI.

Consequences of the Earth's Rotation.—(1) The succession of day and night, (2) the apparent daily motion of the stars, (3) the law that "In whatever direction a body moves on the surface of the earth, there is a force arising from the earth's rotation which deflects it to the right in the northern hemisphere, but towards the left in the southern."

Apparent Daily Paths of Stars when Observed from Different Latitudes.—(1) At the poles the stars appear to describe circles parallel to the horizon; (2) at the equator the stars appear to travel along semicircles perpendicular to the horizon; (3) from middle latitudes are seen (*a*) stars describing apparent circles (circumpolar stars), (*b*) stars which rise, describe oblique paths, and set.

Greenwich Mean Time is time reckoned with reference to the imaginary transit of the "mean" sun over the meridian of Greenwich Observatory. At the moment of transit, clocks and watches keeping Greenwich time should indicate twelve o'clock.

Local Time is reckoned with reference to a local meridian; if the transit of the "mean" sun is used, *local mean noon* is obtained, but if the true sun is observed, *apparent noon.*

Relation between Time and Longitude.–

Longitude	Time
$15''$	1 second
$1'$	4 seconds
$15'$	1 minute
1°	4 minutes
15°	1 hour
90	6 hours.

When it is noon at Greenwich, it is forenoon (a.m.) at westward places and afternoon (p.m.) at eastward.

Daily Variations of Sun's Altitude.—From rising, the sun's altitude increases to noon, when it is greatest; it then decreases until the sun sets. On this account the length of the shadow of an upright pole diminishes to noon, when it is shortest, and then increases until sunset. **True Noon** occurs when the sun is due south, or at the point of maximum altitude for the day.

A Solar Day is the interval between two successive transits, or southings, of the sun across the same meridian; it varies in length.

The Sidereal Day is the interval between two successive transits of a star across the same meridian; it always has the same length.

A Mean Solar Day is the interval between two successive transits of an imaginary, or "mean" sun, over the same meridian; its length is the average of all the true solar days in a year.

Sidereal Time is time reckoned with reference to the stars, or, more correctly, with reference to a particular point in the sky, known as the vernal equinox.

Apparent Time is time reckoned with reference to the true sun; it is indicated by sundials.

Mean Time is time reckoned with reference to the mean or imaginary sun; it is the time given by clocks.

The Equation of Time is the difference between apparent and mean time on any day of the year.

A Sidereal Year is the interval between two successive conjunctions of the sun with a given star; its length is 365 days 6 hours 9 minutes 9 seconds.

A Tropical or Equinoctial Year is the interval between two successive vernal equinoxes; its length is 365 days 5 hours 48 minutes 46 seconds, or very nearly $365\frac{1}{4}$ days.

The Civil Year consists of 365, or, in the case of *leap year*, 366 days; the average length is thus $365\frac{1}{4}$ days. The correction at the rate of $\frac{1}{4}$-day per year is, however, too large, so three leap years are omitted in 400 years.

Questions on Chapter XI.

(1) Describe a sundial, and show how dial time differs from local time. (1896.)

(2) State what you know of the equation of time—

(*a*) In relation to its amount at different times of the year.

(*b*) In relation to its use in determining the moment of mean noon. (1895.)

(3) State the apparent daily movements at London of stars situated near north declination 90°, 51°, 39°, on the equator, and near south declination 20° and 38°. (1895.)

(4) What is sidereal and what is mean time? (1892, 1889.)

(5) State an experimental proof of the earth's rotation. (1891.)

(6) What is the "equation of time," and what use is made of it? (1890.)

(7) What differences occur in the apparent paths of the stars across the sky as we proceed from the equator to the pole? What is the cause of this difference? (1889.)

(8) Explain the relation between longitude and time. When it is noon at Greenwich, what time is it at a place in 30° west longitude?

CHAPTER XII

THE SUN, THE EARTH'S REVOLUTION, AND THE MOON

The Sun.—The student has already learnt to regard the sun as the source of all the forms of energy which we have found to exist on the earth. He has seen that this energy leaves the sun as radiations, which by processes of transmutation become known to us here under the forms of heat, light, chemical action, and so on. It is desirable that we should now inquire further into the nature of the sun, and endeavour to answer such questions as—What is the sun? What is its density? What is its distance from us? and other questions.

What is the Sun?—The sun is the nearest *star* to the earth. We learn in a general way to regard the sun as something distinct from a star because of his comparative nearness to us. When the heavens are illuminated by this glorious orb, the light which he sheds in every direction is of such dazzling splendour that the feebler rays from the other stars are extinguished in comparison, though many of them are probably larger than the sun, but are at such prodigious distances that the light which we receive from them is insignificant. Take an example, we receive ten thousand million times more light from the sun than from a bright star called α Lyræ, but this star is more than a million times further from us!

This beneficent source of all our light and heat is very different in its nature from the earth. Not only is it of grander proportions, but in a far different physical condition from that of our planet. We have seen that the earth is a spherical body with a circumference of under 25,000 miles, possessing a solid crust,

though more or less liquid in parts of its interior; that it is surrounded by an atmosphere containing chiefly nitrogen and oxygen, and of diminishing density as we travel outwards from its centre. The sun, though it is composed of intensely hot vapours and gases, also diminishes in density from the centre outwards. The elements of which it is composed are now all known to take part in the composition of the earth. But it was only in the year 1895 that one of them, which was long ago recognised in the sun by Prof. Lockyer and called by him *helium*, was discovered in a comparatively rare mineral, *clevite*, by Prof. Ramsay.

The outermost material composing the sun is called its *corona*. Beneath it is a concentric stratum called the *chromosphere*, underlying which we have a layer, oftentimes containing mighty chasms, and called the *photosphere*. These huge depressions are the well-known *sun-spots*, which are sometimes sufficiently extensive as to be visible to the naked eye.

Density of the Sun.—From the nature of the materials constituting the earth the student would expect to find that the density of the sun is very much less than that of the earth. While the volume of the sun is one and a quarter million times as great as that of the earth, that is, this number of earths would be necessary to build up a globe as large as the sun, its weight is only something over three hundred thousand times as great. But the definition of density (p. 22) is the relation of the mass to the volume, and consequently we get the proportion :—

$$\begin{matrix}\text{Earth's}\\\text{density}\end{matrix} : \begin{matrix}\text{Sun's}\\\text{density}\end{matrix} = 1 : \frac{300{,}000}{1\frac{1}{4}\text{ million}} = 1 : \tfrac{1}{4} \text{ roughly.}$$

The sun's density is, therefore, only one quarter that of the earth, which, as we have seen, is 5·6, and thus we get the value 1·4 as the density of the sun. This means that the sun is about one and a half times as heavy as it would be if it were composed of water, or about the same weight as a globe of the same size made of coal would be, for the density of coal is just about 1·4.

Relative Sizes of the Sun and Earth.—

EXPT. 173.—Cut a circular piece of cardboard having a diameter of four inches. Pass a piece of stout wire, just over a foot long, through the centre of the card, and fix it at a distance of six inches from one end

of the wire. Similarly, fix a larger card at a distance of twelve inches from the same end of the wire. Fasten a second wire to the end of the first, and freeing it from kinks and having smoothed it until quite straight, let it rest on the smaller card and touch the larger one. Rotate it on the edge of the smaller card, and cause it to mark out a circle on the larger card. Measure the diameter of the circle so marked out, and notice that its diameter is eight inches. Since light travels in straight

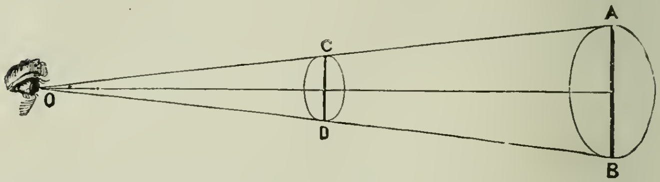

FIG. 80.—To show that the apparent sizes of circles depend on their distances from the observer's eye.

lines, it is clear that an eye placed at the end of the wire would be able to see nothing inside the circle on the large card if the smaller one were interposed.

The student will now understand Fig. 80, which shows that the apparent sizes of the circles, or their diameters, depend upon their distance from the observer's eye. If a halfpenny, the diameter of which is exactly one inch, be placed at a distance of nine feet from the eye, it appears of just the same size as the sun's disc. If we know the distance of the sun from the eye, this gives us a means of comparing the diameters of the halfpenny and the sun, thus :—

$$\text{Distance of halfpenny from the eye} : \text{Distance of the sun} = \text{Diameter of halfpenny} : \text{Diameter of sun.}$$

We can take the distance of the sun as 93 millions of miles, though, as will be seen, this distance is not always the same. Our proportion thus becomes :—

$$9 \text{ feet} : 93{,}000{,}000 \text{ miles} = 1 \text{ inch} : \text{diameter of the sun.}$$

The diameter of the sun works out to be about 866,000 miles, or about 108 times greater than the earth's diameter, which is very nearly 8,000 miles (Fig. 81).

It must be clearly understood that this refers only to the relative *diameters*. If we wish to compare the *areas* of the earth's disc with that of the sun we shall get the proportion of

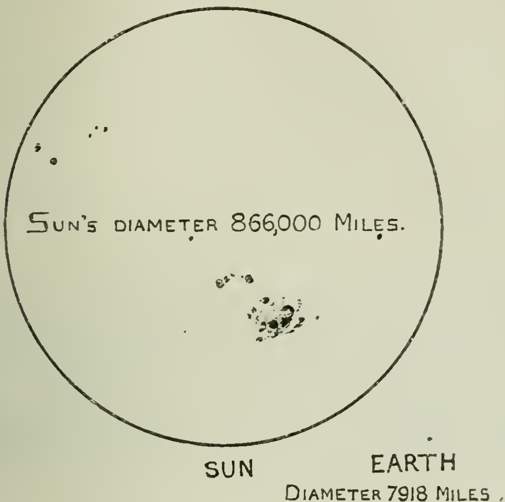

FIG. 81.—Relative Sizes of the Sun and Earth.
From Gregory's Physiography Slides. (G. Philip and Son.)

1 to the *square* of 108, *i.e.*, 108 × 108; and similarly the proportion of their *volumes* is 1 to the *cube* of 108, *i.e.*, 108 × 108 × 108.

Revolution of the Earth round the Sun.—The earth in addition to its regular rotation upon its axis, has another motion which carries it round the sun on a fixed path, called its *orbit*, once in a year. Attention has already been called to the universal law of gravitation as enunciated by Newton, which expresses the fact that every mass attracts every other with a force varying as the product of their masses and inversely as the square of the distance between their centres. In addition to this it has been seen that the inertia possessed by all moving matter gives it a tendency to continue its motion in a straight line.

The sun is 330,000 times heavier than the earth, and had we only the first of the above laws to govern the earth's movement in space, it is manifest that the earth would be attracted with so great a force by the sun that it would be drawn in towards it and would become part of the sun. But there is at the same time the tendency which the earth possesses to move off in a straight line into space. The earth's orbit represents, therefore, the resultant of these two forces which are continually acting upon it. It is for these reasons, too, that the earth moves round the sun, and not the sun round the earth.

But the earth is neither the only body, nor, indeed, the most important one, moving round the sun in this way. There are eight large bodies, called *planets*, travelling on regular paths, at varying distances, round the sun. In addition there are about four hundred small planets, of which the student may read in books on astronomy. The large ones in order of their distance from the sun are :—

1 Mercury	5 Jupiter
2 Venus	6 Saturn
3 Earth	7 Uranus
4 Mars	8 Neptune.

Distance of the Sun from the Earth.—The velocity with which light waves travel has been determined in several ways, for a description of which we must refer the student to books on Physics. The result of these experiments gives this velocity as 186,000 miles per second. Knowing this, the observations, first made by the Danish astronomer, Roemer, upon the moons of the planet Jupiter provide us with a means of determining the sun's distance from us. Jupiter has five moons, which complete their journey in different times, but in every case in a much shorter period than that taken by our satellite.

Further, they revolve round Jupiter in a plane nearly coincident with that of the planet's orbit round the sun, and consequently scarcely a day goes by without one or other of these moons passing into the shadow of the planet thrown by the sun, and so becoming invisible to us. The time at which the disappearance of the moon will take place can be calculated exactly for months or years in advance, and were the earth at rest in relation to the sun no complication would arise. If, now, when

the earth and Jupiter are on the same side of the sun, we notice the time of disappearance of one of the moons into the planet's shadow, and then calculate the time at which the phenomenon should happen six months hence, we find when the half-year has elapsed that the observed time of this moon's passage into the shadow and the calculated time do not agree. It occurs about sixteen minutes thirty seconds later. The only way in which this can be accounted for is to suppose that the earth's position respecting the sun has undergone a change, and were there no other reason for knowing that such an alteration in position had taken place, this would be enough. The earth has travelled half of its annual journey on its path round the sun, and the light from the vanishing moon has to travel across the earth's orbit, that is, the extra distance from E to E′ in Fig. 82,

FIG. 82.—To explain Roemer's observations of Jupiter's moons.

before it can reach the observer and record its disappearance on his retina. When another six months have passed the observed and the calculated times agree. The student will see that the journey across the earth's orbit is completed by light travelling at the rate of 186,000 miles a second in 16′ 30″ or 990 seconds, and consequently the distance travelled must be $186,000 \times 990 = 184,140,000$ miles; and, if we suppose the sun to be midway between these two positions of the earth, which, however, it is not, the distance of the sun would be about 93,000,000 miles.

It is worth while to point out that the degree of accuracy obtainable by this method depends upon that of the value taken for the velocity of light, and as we have only employed an approximate value, our result for the sun's distance is only roughly correct.

Inclination of the Earth's Axis.—Imagine a plane passing through the centre of the earth and the centre of the

sun; the earth's centre will fall in this plane at all times of the year, that is, whatever the position of our planet on its orbit may be. This plane, containing the earth's orbit, is called the *plane of the ecliptic.* Or, putting the same fact in another way, we can think of the earth and sun as floating in a boundless ocean, each of them being half immersed, or sunk as far as their centres. Under these circumstances the surface of such an ocean would be the plane of the ecliptic. The earth would have to be supposed to float in such a manner that its axis made an angle of $66\frac{1}{2}°$ with the surface of the ocean, because the axis of

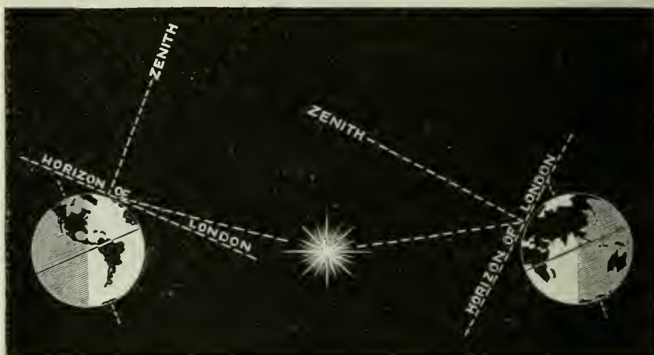

FIG. 83.—To explain why the Mid-day Sun, seen from London, is low down in the sky in Midwinter and high up in Midsummer.

the earth is inclined at an angle of $66\frac{1}{2}°$ to the plane of the ecliptic. The plane containing the earth's equator is known as the plane of the equator, and from the above inclination it follows that *the plane of the equator and the plane of the ecliptic are inclined to one another at angles of* $23\frac{1}{2}°$.

Some Consequences of the Inclination of the Earth's Axis.—The earth's axis, whatever its position on its orbit, is always inclined at the same angle. Or, at the various positions of the earth in its annual journey round the sun the directions of the axis always remain parallel to one another. The axis always seems to point in the same direction in space,

and near the point in the sky to which the northern extremity is directed.

It is due to this inclination that the mid-day sun has a different altitude at different times of the year. Fig. 83 shows the positions of the earth at midwinter and midsummer respectively. At the former of these times, when the earth is in the left-hand position of the figure, the north pole of the earth's axis points away from the sun as shown. To an observer at London it is clear that the sun will appear very near the

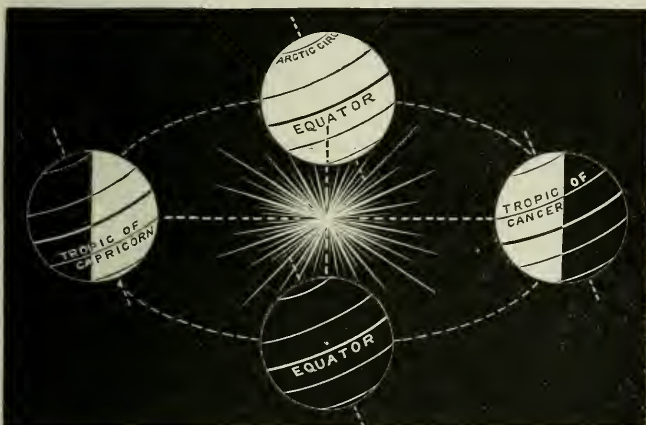

FIG. 84.—Explanation of the Variation in Length of Days and Nights throughout the Year.

horizon. When, six months after, the earth has reached the right-hand position in the figure, the north pole of the axis points towards the sun, and the observer in the same place as before will now see the sun much nearer the zenith than when the earth was in its midwinter position.

Variation in Length of Days and Nights throughout the Year.—Fig. 84 shows the earth in four positions on its orbit, and from what has been said in the preceding paragraph the student will recognise the left and right-hand positions as those of midwinter and midsummer respectively. We will

begin with the first of these, and refer only to the condition of things in the northern hemisphere, reminding the reader that it only remains for him to exactly reverse this order to know the changes which occur south of the equator. In whatever position the earth may be, one-half of it will always be illuminated ; and were the axis of the earth perpendicular to the plane of the ecliptic the day and night would always be just twelve hours long. Supposing the earth in its midwinter position, we must think of it as continually spinning round upon its axis, and we will imagine ourselves on some middle parallel of latitude, say, at London. Our latitude, *i.e.*, our distance north of the equator, remains the same, and hence during a complete rotation we describe a circle round the earth parallel to the equator. Now, if such a circle be imagined round the earth when it is in this left-hand position, it is quite clear that a much larger part of the circle will be in the dark than will be in the light. This is the same as saying that the observer is in the dark for a much longer time than he is in the light, or for him the nights are longer than the days. In this position the north pole and places $23\frac{1}{2}°$ from it never come into the light, or places within the circle called the *Arctic circle*, have a continuous night.

When, six months later, the observer has been carried with the earth round to the right-hand position in the figure, the greater part of a circle, representing his path as the earth rotates, will be in the light, or the days will be longer than the nights. Here places within the Arctic circle never get out of reach of the sun's rays, or for them there is perpetual day.

At the two places on the top and bottom of the figure, midway between the extreme positions described, just one-half of the circle marked out by the observer during a single spin of the earth is in the light, and just one-half in the dark. That is, in these two positions the days and nights are exactly equal in length. These positions are called *equinoxes*, the one, when the earth is on its way towards midsummer, is called the *spring* or *vernal equinox*, and occurs on March 22nd. The other, when the earth approaches winter, is the *autumnal equinox*, which falls on September 23rd. This condition of things obtains when the earth is on the line along which the plane of the equator intersects the plane of the ecliptic, and is known as the *line of equinoxes*.

Experiment illustrating Variation in the Length of Day and Night.—

§ EXPT. 174.—Take a knitting needle and incline it at an angle of $23\frac{1}{2}°$ on a piece of board, pass it through the centre of an orange, and move the orange round a lamp. When in the position that the inclination of the knitting needle is towards the lamp, notice that a white bead on the upper surface of the orange is illuminated longer than one on the lower surface when the orange is rotated round the knitting needle. Also notice that near the vertical pole a point is always illuminated and near the south it is never illuminated. Move the orange so that the needle points away from the lamp, and show that the illumination of the southern and northern hemispheres is just reversed. Move the orange half-way between these two positions, always keeping the needle pointing in one direction, and notice that both hemispheres have equal illumination. The duration of day and night is analogous to this.

The Seasons.—The alternation of the seasons is also the outcome of the inclination of the earth's axis. During the day our planet is continually receiving heat from the sun, which it as regularly radiates into space during the night. Now, *if the days are longer than the nights*, it is evident that more heat is received during the hours of light than is radiated throughout the night, or *there is a net gain of heat*. Whereas, if the opposite holds true, and the nights are longer, there is a *net loss of heat*.

Referring again to Fig. 84, as the earth moves round its orbit in the opposite direction to the hands of a watch, from its midwinter position through the spring equinox towards midsummer there is a gradual increase in the lengths of the days and consequently of the net gain of heat, and *the earth gets warmer and warmer*; while after the midsummer position has been passed and the earth is moving on through the autumnal equinox towards midwinter again there is a net loss of heat and *the earth becomes gradually colder*.

During summer in the northern hemisphere the sun appears in the zenith, or vertical, at places $23\frac{1}{2}°$ north of the equator, and this parallel of latitude is called the *Tropic of Cancer*. The same is true of places $23\frac{1}{2}°$ south of the equator during winter in the northern hemisphere, and this parallel is called the *Tropic of Capricorn*.

Experiments illustrating the Cause of the Seasons.—

§ EXPT. 175.—Take two similar thermometers with lamp-black on the surface of the bulbs, and place them side by side opposite a bright lamp. Notice that they show the same temperature when both are

screened from the lamp. Expose one for *one* minute and the other for *two* minutes to the rays from the lamp, and notice that the mercury in one rises higher than in the other. Repeat the experiment, but change the two thermometers to which the long and short exposures are given to show that the difference in the rise of the mercury has nothing to do with the thermometers. The longer the exposure the higher is the temperature. Similarly, think of the conditions explained above.

§ Expt. 176.—Take two pieces of sensitive albuminised paper, say one inch square, place them side by side, one with its sensitive surface vertical and the other inclined at an angle to the vertical. Burn two inches of magnesium ribbon, at a distance of a foot from the squares of paper, in such a position that the light falls normally on the vertical piece of paper. This square will be more blackened than the other, showing that light acts more energetically when a surface is at right angles to the direction of the rays.

Remember the sun is on an average much higher in the heavens in summer than in winter, and hence this light has more power to heat the earth on that account. Think of this in connection with the seasons.

Kepler's Laws.—The astronomer Kepler showed that the planets revolve round the sun in accordance with three rules, which he stated as follows :—

1. The planets revolve round the sun in orbits which have the form of ellipses. The sun is situated at one of the foci of the ellipse.

2. The areas swept over by the radius vector of each planet are equal in equal times.

3. If the squares of the times of revolution of the planets round the sun be divided by the cubes of their average distance from the sun, the quotient will be the same for all the planets.

Kepler's First Law.—Before the student can understand this law he must first learn some of the properties of the ellipse.

Expt. 177.—Fix a pin into a piece of paper and pass a loop of thread over it. Into the other end of the loop push a piece of pencil. Keeping the thread tight, draw a line on the paper round the pin. Remove the thread, and notice that a *circle* has been described with the pin as its centre.

Expt. 178.—Fix two pins into the paper, and pass the loop over both pins, and again move the pencil round as before. Notice that this figure is not a circle. It is an *ellipse*, and the pins are situated at points called the *foci* (Fig. 85).

Expt. 179.—Repeat the last experiment several times with the pins nearer and nearer together. Notice that the closer the pins are together the more nearly does the ellipse approach the shape of a circle. We can look upon a circle as an ellipse where the two foci have moved up together until they occupy the same point.

The first law, then, simply states that the figures which the planets trace out as they move round the sun are similar in

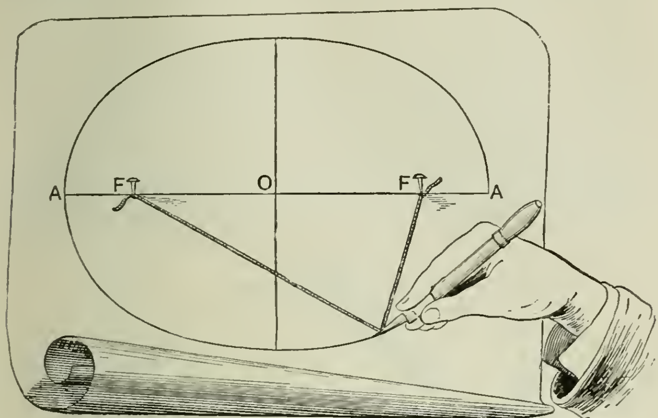

FIG. 85.—To show the Construction of an Ellipse. F, F, are the Foci

shape to that marked out by the pencil in Expt. 178, and that the sun occupies the position of one of the pins round which the loop of thread is passed. If this is true of all the planets it must be true of our earth, and consequently we must be nearer to the sun at certain times than at others. Further, if we are nearer to the sun at some times of the year than at others, the sun ought to appear larger then than when we are as far away as we can be. This is found to be the case. If the diameter of the sun is measured at noon on Midwinter day, and again at noon on Midsummer day, it is found to appear larger on the former occasion. Fig. 86 gives an idea of the amount of this difference.

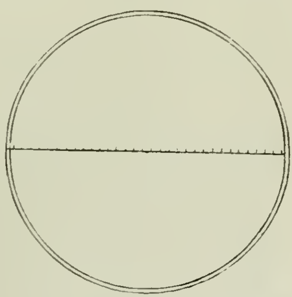

FIG. 86.—To show the difference in the apparent size of the Sun on Midwinter and Midsummer Days.

Kepler's Second Law.—The areas swept over by the radius vector of each planet are equal in equal times. By the radius vector is meant an imaginary line joining the centre of the planet with that of the sun. Fig. 87 shows that it cannot remain of the same length. When the planet is nearest the sun, or as it is called, in *perihelion*, the radius vector is much shorter than when it is farthest removed, or in *aphelion*. The shaded portions of the figure represent areas moved over in equal times by this imaginary line, and the second law states that they are all equal. It follows as a necessary consequence that the distance P_2 P_3, moved by the earth, for example, when this planet is near

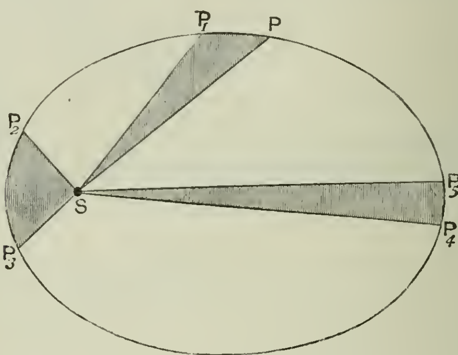

FIG. 87.—To explain Kepler's Second Law.

the sun, must be much greater than P_4 P_5, the distance traversed when the earth is in aphelion. But these distances are travelled in the same period of time, and consequently Kepler's second law is tantamount to saying that the planet moves more quickly in perihelion than when in aphelion. This is found to be the case with the earth, for whereas the passage from the autumnal to the spring equinox takes 179 days, that from the spring equinox to the autumnal takes seven days longer.

Kepler's Third Law.—If the squares of the times of revolution of the planets round the sun be divided by the cubes of their average distance from the sun, the quotient will be the same for all planets.

The time of revolution of a planet round the sun is called its *period*. This law is best understood by an example, say, the Earth and Saturn. Following the rule, we can write—

$$\frac{(\text{Earth's period})^2}{(\text{Earth's average distance})^3} = \text{some quotient, say } x$$

$$\frac{(\text{Saturn's period})^2}{(\text{Saturn's average distance})^3} = \textit{same} \text{ quotient } x$$

$$\frac{(\text{Earth's period})^2}{(\text{Earth's average distance})^3} = \frac{(\text{Saturn's period})^2}{(\text{Saturn's average distance})^3}$$

Therefore, knowing the Earth's period and its average distance, we could find Saturn's average distance if we knew its time of revolution. The Earth's period is one year and Saturn's twenty-nine and a half years, and from the last equation above we can write—

$$\begin{matrix}\text{Square of} & & \text{Square of} & & \text{Cube of} & & \text{Cube of}\\ \text{Earth's} & : & \text{Saturn's} & = & \text{Earth's} & : & \text{Saturn's}\\ \text{period} & & \text{period} & & \text{distance} & & \text{distance}\end{matrix}$$

or

$$1 : 29\tfrac{1}{2} \times 29\tfrac{1}{2} = 1 \times 1 \times 1 : \text{Cube of Saturn's distance}$$

that is,

$$\text{Cube of Saturn's distance} = 870\tfrac{1}{4} \text{ times Earth's distance}$$

Saturn's distance $= 9\frac{1}{2}$ (very nearly) times the Earth's distance.

The Moon is a smaller body than the earth, revolving round it thirteen times during one terrestrial revolution round the sun. Like the planet upon which it attends as a *satellite*, it has besides this motion of revolution one of rotation as well. It completes a single rotation in exactly the same period of time during which it travels once round the earth. The result is that we never see more than one side of the moon.

At the time when the moon appears largest to us, which we call *full moon*, it would seem to be the largest of the heavenly bodies. This is not by any means actually so, the appearance being caused by the nearness of the moon to us. It is the nearest heavenly body. Its distance from the earth is roughly ten times the circumference of the earth, the actual distance varying between 222,000 miles when she is nearest to us, or in *perigee*, and 253,000 miles when she is as far away as she can be, or in *apogee*. The average distance is 239,000 miles. The variation of the moon's distance from the earth is because the orbit on which she travels is elliptical, as in the case of the planets. From what has been said in another place of the effect

of nearness upon the apparent size of a body, the student will not be surprised to learn that the moon has a diameter of only one-quarter that of the earth.

This being so, it would require forty-nine moons to build up a planet of the size of our earth, and if we bear in mind what was said in speaking of the comparative sizes of the earth and sun, we shall see what a very small body the moon is in the solar system.

Nor is its density as high as that of the earth, being only about three and a half times as heavy as a moon made entirely of water would be, while the earth is five and a half times as

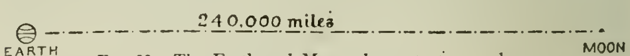

FIG. 88.—The Earth and Moon, drawn to true scale, both as regards size and distance.

heavy as a similarly constituted earth. Naturally, then, its weight will be less than one forty-ninth that of the earth, and it is found that it would require eighty moons to weigh as much as the earth.

Measurements of the Moon's Distance and Diameter.—It is well known that surveyors are able to determine the distance of an object without directly measuring it with a tape measure. To accomplish this, they accurately measure off a straight line of a convenient length, say, one hundred yards, and point their theodolite towards the object from each end of this base-line. The angle between the direction of the theodolite and the direction of the base-line is thus determined for each position. An experiment will illustrate how this pair of pointings enables a distance to be determined.

§ EXPT. 180.—Take a lath, say a yard long, and place it on a table, on which also some object is placed at a distance. From each end of this lath point another lath towards the object, and rule two lines on pieces of paper placed between them to show the inclination of the two pointers to the first lath. Make on the blackboard a line to represent the yard lath, and at each end of it draw the angles obtained above and produce the lines to meet. The intersection of these lines represents the position of the object, and its distance measured on the same scale as the line representing the yard lath will give us the distance of the object.

It is easy to understand that the method illustrated by this experiment can be applied to determine the distance of the

moon. There are many practical difficulties and details which need not, however, be described here. Suffice it to say that delicate instruments at two observatories so far apart as Greenwich and the Cape of Good Hope are pointed at the moon. The distance between these observatories can be calculated, and it constitutes the base-line. Observations are made to find the angle between the base and the direction in which the moon is seen at the two places ; and these observations, together with the length of the base, enable the distance of the moon to be calculated in much the same way as that used by surveyors and illustrated by the preceding experiment.

The full moon looks about the same size as the sun ; as a matter of fact, the moon's mean angular diameter is 31′ and the sun's 32′. It will be remembered that in explaining the principle of determining the actual length of the sun's diameter (p. 177) the fact was utilised that when two discs appear to have the same size their real diameters are proportional to the distances from the point of observation. Taking, therefore, the apparent diameters of the sun and moon as equal, we have the proportion—

$$\begin{matrix}\text{Distance} \\ \text{of Sun}\end{matrix} : \begin{matrix}\text{Distance} \\ \text{of Moon}\end{matrix} = \begin{matrix}\text{Diameter} \\ \text{of Sun}\end{matrix} : \begin{matrix}\text{Diameter} \\ \text{of Moon.}\end{matrix}$$

Or, using round numbers—

$$93{,}000{,}000 : 240{,}000 = 866{,}000 : \text{Diameter of Moon.}$$

$$\text{Hence, Moon's diameter} = \frac{240{,}000 \times 866{,}000}{93{,}000{,}000} = 2{,}234 \text{ miles.}$$

The exact length of the diameter is 2,163 miles.

Phases of the Moon.—The moon travels round the earth once a month, the interval of time between two successive full moons being 29½ days. The moon has no light of its own, but the sun is continually shining upon its surface, so that the light which the moon appears to possess is really reflected sunlight. We do not, however, always see the illuminated half of our satellite, and the consequence is that we get the phases or changes of the moon familiar to every one who has sight. Exactly why these changes should occur can be illustrated with simple apparatus.[1]

[1] A set of simple apparatus for illustrating lunar phases and other celestial phenomena referred to in this book can be obtained from Messrs. Chapman and Hall.

EXPT. 181.—Place a lighted lamp upon a table to represent the sun. At a short distance from it, place a small terrestrial globe and procure a white india-rubber ball to represent the moon. Show that by carrying the ball around the earth the phases of the moon can be imitated.

At new moon the illuminated half of the lunar surface is turned away from the earth, so nothing is seen of our satellite. As the moon travels around the earth, first a crescent of the

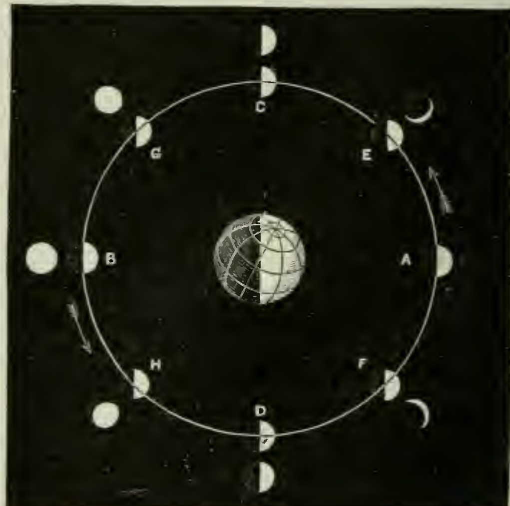

FIG. 89.—Phases of the Moon. The Sun's Rays come from the right-hand side. A, new moon ; B, full moon.

bright surface becomes visible. Day by day it increases in size until full moon is reached, in which case we see the whole of that part of the moon upon which the sun is shining. From this point the bright face wanes and eventually the condition of new moon is again reached. The accompanying illustration (Fig. 89) will help the student to trace these changes throughout the moon's revolution around the earth.

Rotation of the Moon.—The "man in the moon" always appears to have the same expression ; in other words, the same

face of the lunar surface is always seen by us. This is because the moon rotates on an axis in the same time that it revolves around the earth. When, for instance, the moon has travelled over a quarter of a revolution it turns on its axis by a quarter of a rotation and so prevents us from seeing the new lunar scenery which would, but for this compensating cause, become visible.

EXPT. 182.—Push a knitting needle horizontally through the india-rubber ball used in the preceding experiment. Make a blotch of ink upon the ball to represent a marking upon the lunar surface. Carry the ball around the globe in the same way as was done in illustrating the phases of the moon. It will be seen that in order to keep the blotch of ink facing the globe the knitting needle must turn completely round while the ball through which it is stuck performs its journey. If the needle is kept constantly parallel, all parts of the ball are turned in succession towards the globe.

Eclipses of the Moon.—As was stated in dealing with proofs of the spherical form of the earth, an *eclipse of the moon*

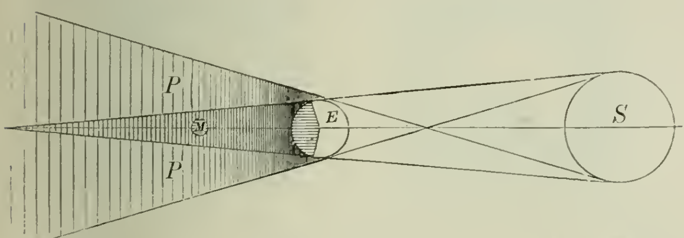

FIG. 90.—Eclipse of the Moon. S, the Sun; E, the Earth; M, the Moon.

is the result of the earth coming between the sun and the moon (Fig. 90). Eclipses are caused by the fact that light travels in straight lines, producing clearly-defined shadows of objects in its path.

EXPT. 183.—Cast a shadow of a sphere on to a screen, using a small source of light, such as a candle-flame. Notice that the shadow is circular and of equal darkness throughout.

EXPT. 184.—Substitute a lamp, with a ground glass globe larger than the sphere, for the candle in the last experiment. Notice that the shadow on the screen is made up of two parts, an inner very dark circular patch called the *umbra*, while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the *penumbra*.

Since the sun is the source of light casting the shadow of the earth into which the moon travels at an eclipse, it is plain that we have the condition of things represented in Expt. 184 taking place on a large scale. The moon first travels into the penumbra and is still visible though her brightness is diminished. When the umbra is reached, however, the part of the moon within it becomes quite invisible, and it is at this stage we have the appearance represented in Fig. 70 where the circular outline of the earth's shadow is seen. Even after the moon has passed entirely into the umbra a dull red disc can still be made out. This is because sunlight is refracted by the earth's atmosphere and so made to strike upon the moon's surface, which reflects it to us. The coppery colour is due to the passage of these rays through the earth's atmosphere.

So far as we have proceeded at present there is no reason why we should not have a lunar eclipse at every full moon. If the plane in which the moon revolves round the earth was coincident with that in which the earth travelled round the sun, there would be an eclipse at each full moon. But the moon's orbit is inclined to the plane of the ecliptic, and it therefore happens that on some occasions of full moon the earth's satellite is above or below the shadow cast by the earth and no eclipse occurs. At other times the moon partially passes through the umbra and we have what is known as a *partial eclipse*. It is only when the centres of the sun, earth, and moon are in the same plane that a total eclipse can occur, and this only happens when the three bodies are in the same straight line at the same time that the moon is at the points where the moon' s orbit cuts that of the earth, *i.e.*, at the *nodes*.

Eclipses of the Sun.—These *solar eclipses* occur when

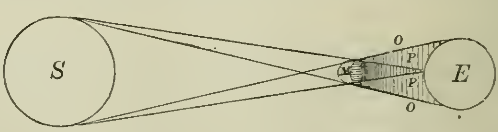

FIG. 91.—Eclipse of the Sun. S, the Sun ; M, the Moon ; E the Earth.

the moon comes between the sun and the earth, that is, at *new* moon (Fig. 91).

EXPT. 185.—Using the lamp with a large globe as in the last experiment, cast a shadow of a very small sphere. Notice that the shadow comes to a point, as can be shown by moving the screen slowly from the sphere, when the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of the two previous experiments are *diverging* ones.

The last experiment represents the formation of a solar eclipse. The sun casts a shadow of the much smaller moon and the shadow sometimes falls upon the earth. But the shadow will evidently only extend over a small part of the earth's surface, that is to say, the eclipse of the sun will not be visible everywhere upon the earth, but only at certain places where the moon is in the way between the observer and the sun.

We have seen that the moon is sometimes nearer the sun than at others. *Total* solar eclipses, when the sun is quite blotted

FIG. 92.—Annular Eclipse.

FIG. 93.—Partial Eclipse.

out by the moon, occur when the moon is in perigee and at a node at the same time. If the moon is in apogee, and at a node at the same time, the shadow cast by the moon falls short of the earth, and consequently the appearance to an observer in the line of the shadow is different. The moon cuts off all the light of the sun excepting a ring of light surrounding the circle of darkness, and we have what is called an *annular eclipse* (Fig. 92). Sometimes the moon does not pass in a direct line between the sun and the earth, in which case the sun is only partially covered, as in Fig. 93.

The phenomena observed during a total solar eclipse are very striking. The moon's disc first appears on the western edge of the sun and gradually covers up the whole surface.

When the sun is thus totally obscured there is very little light, and the bright stars can be seen as at the beginning of night. Around the sun and extending in luminous sheets and streamers for thousands of miles is seen the *solar corona*. In addition to this halo, a number of red-coloured "prominences" or solar flames may be seen shooting out from the sun behind the dark edge of the moon.

These prominences consist chiefly of hydrogen gas and helium, and it is to investigate them and the solar corona that astronomers send out eclipse expeditions. The phenomena described are only observable during total obscuration of the sun, and as totality only lasts four or five minutes, the opportunities to investigate them are utilised to the fullest extent.

Chief Points of Chapter XII.

The Sun.

Mean distance from the earth 93,000,000 miles.
Variation of the distance between January and June, owing to the revolution of the earth in an elliptic orbit, 3,000,000 miles.
Diameter 866,400 miles.
Ratio of diameter to the earth's 109·3.
Surface compared with the earth 11,940.
Volume, or cubic contents, compared with the earth 1,305,000.
Mass, or quantity of matter, compared with the earth 330,000.
Mean density compared with the earth 0·253.
Mean density compared with water 1·406.
Force of gravity compared with that on the earth 27·6.
Rotation period 25·38 days.

Simple Proof of the Earth's Revolution.—(1) The sun is 330,000 times heavier than the earth, and gravitation rules that in such a case the centre of revolution is 330,000 times further from the earth than from the sun. (2) The periodic variations in the intervals between successive eclipses of Jupiter's satellites.

The Inclination of the Earth's Axis is $23\frac{1}{2}°$ out of the perpendicular to the plane of revolution, or $66\frac{1}{2}°$ with reference to that plane.

The Shape of the Earth's Orbit has been proved to be that of an ellipse by daily measurement of the sun's angular diameter throughout the year. In January the apparent diameter is greatest, and in June least.

Consequences of Revolution and Axial Inclination.—(1) The annual variations in the noonday altitude of the sun at any one place. (2) Variations in the length of days and nights in different latitudes and at different times of the year. (3) The seasons.

Kepler's Laws.—(1) Each planet revolves in an ellipse with the sun at one of the foci. (2) Equal areas are swept over in equal times by a line joining the planet to the sun. (3) The squares of the revolution periods are proportional to the cubes of the mean distances.

The Moon.

Diameter, 2,163 miles: compared with earth's 0·27.				
Surface, compared with earth's $\frac{1}{14}$.				
Volume,	,,	,,	,,	$\frac{1}{49}$.
Mass,	,,	,,	,,	$\frac{1}{80}$.
Density,	,,	,,	,,	0·6.
Density,	,,	,,	water,	3·4.
Force of gravity,	,,	earth's		$\frac{1}{6}$.
Average distance,		239,000 miles.		
Greatest	,,	253,000	,,	
Least	,,	222,000	,,	

Questions on Chapter XII.

(1) State the general features of the earth's orbit. (1896.)

(2) State a proof that the earth moves round the sun. (1892, 1895.)

(3) Why are the days longer in summer than in winter? Give a diagram explaining the sun's altitude at noon on the longest and shortest days. (1889, 1895.)

(4) How has the shape of the earth's orbit been determined? (1892, 1894.)

(5) Why are the days longer in summer than in winter? Explain the difference noted at these seasons—

(*a*) In the sun's declination.

(*b*) In the place of sunrise and sunset.

(6) Give an account of the apparent movements of the stars depending upon—

(*a*) The earth's revolution on its axis.

(*b*) The earth's rotation round the sun.

(7) What difference is observed in the place of the rising and setting of the sun—(1) at different times of the year at any place in the British Isles; (2) at the summer solstice in different parts of the northern hemisphere?

(8) Given that the distance of the sun is 93,000,000 miles, describe the principle of determining the sun's diameter.

(9) How is the succession of the seasons accounted for?

(10) Explain the phases of the moon.

(11) Write out Kepler's Laws.

(12) Give diagrams showing the relative positions of the sun, earth, and moon during total eclipses of the sun and moon.

CHAPTER XIII

THE ATMOSPHERE

Surrounding the earth in every latitude, over land and sea, is a gaseous envelope which is spoken of as the air or the atmosphere. Its presence when at rest is unperceived, though in motion it becomes apparent, since by imparting its velocity to trees and other bodies free to move, it affords a demonstration of its existence. The student has already learnt to regard it as a form of matter, and as consequently possessing weight. The following experiments supply sufficient evidence of its existence and of its weight.

EXPT. 186.—Invert a so-called *empty* bottle under water in the pneumatic trough. Notice the bubbles which rise as the water flows into the bottle. The water displaces the air which thus becomes apparent.

EXPT. 187.—Move quickly across the room with a drawing board in your hands. First hold the board "end on" and then "broad-side on." Notice that in the first case little or no resistance is felt, while in the second, one's motion across the room is considerably impeded.

Weight of the Air.—It is easy to prove by direct experiment that the air has weight.

EXPT. 188.—Fit a one-holed india-rubber stopper into a fairly large glass flask, and fit into the stopper a short tube with a stop-cock upon it. Put a little water in the flask; open the stop-cock; and boil the water. After boiling for a little time, turn off the tap and place the flask on one side to cool. When the flask is cool, weigh it, or counterpoise it. Then open the stop-cock; air will be heard to rush into the flask and as it does so the balance will show an increase of weight.

If the air is completely removed from a flask by means of an air-pump, the difference in the weighings, before and after, will

provide the exact weight of a given volume of air. Thus if the vessel has a capacity of a cubic foot the difference of weight will be found to be nearly an ounce and a quarter.

Pressure of the Atmosphere.—It has been seen that it is a property of all fluids that they communicate pressure in all directions, and consequently it is a character of air. If the atmosphere did not possess this property, a little thought will convince the student that, instead of lying quietly on the ground, a fallen leaf would move off in the direction of least pressure, which would evidently be upwards. It is a consequence of this circumstance, too, that we are able to move about quite freely. Our bodies are subjected to an enormous pressure due to the whole weight of the atmosphere above us, and yet we are quite ignorant of it, at all events under ordinary circumstances. Why is this? The lungs which fill up a large part of our chest capacity are inflated with air, and other inside parts of the body are similarly in free communication with the atmosphere. The inside air is under just the same pressure as that outside, and consequently there is an exact compensation, and we are not crushed, as the student will perhaps have expected we ought to be.

EXPT. 189.—Procure a thin tin can having a neck, into which fits an india-rubber stopper. Take out the stopper and boil a little water in the can. After the water has been boiling for some time, so that the can is practically filled with steam, remove the can from the flame, and quickly put in the stopper as tightly as you can. After a few minutes the can will collapse.

The explanation of the effect produced in this experiment is that as the can cooled, the steam inside was condensed into water, and so occupied a much smaller volume. The pressure which the steam exerted on the inside of the can was thus removed, while the pressure of the air on the outside remained practically the same, the result being that the can was crushed. At the sea-level, under ordinary conditions, the pressure of the air is 15lbs. on every square inch.

The following experiments also illustrate effects of atmospheric pressure :—

§ EXPT. 190.—Moisten a leathern sucker, press it upon a flat stone, and show that it can only be pulled off with difficulty, owing to the pressure of the atmosphere upon its upper surface.

§ EXPT. 191.—Dip the open end of a glass syringe or squirt into a bowl of water. Pull up the piston, and show that the water follows it, owing to the pressure of the atmosphere upon the surface of the water in the bowl. Explain the action of a pump which is very similar.

§ EXPT. 192.—Take a tumbler or cylinder with ground edges and completely fill it with water. Place a piece of stout writing paper across the top and invert the vessel. If the air has been carefully excluded from the cylinder the water does not run out (Fig. 94). Think what keeps the paper in its place.

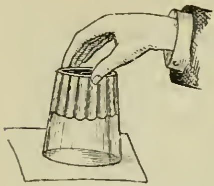

FIG. 94.—Experiment to illustrate the Pressure of the Atmosphere.

Principle of the Mercurial Barometer.—It has been seen that the air has weight, and that it exerts great pressure on the earth's surface ; we have now to learn how this pressure is measured.

EXPT. 193.—Procure a barometer tube and fit a short piece of india-rubber tubing upon its open end. Tie the free end of the tubing to a glass tube about six inches long open at both ends. Rest the barometer tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 95.

The mercury in the long tube will be seen to fall so as to leave a space of a few inches between it and the closed end. The distance between the top of the mercury column in the closed tube and that in the open tube will be found to be about thirty inches.

Referring to Fig. 95, it is clear that there is a column of mercury supported by some means which is not at first apparent, or else the mercury would sink to the same level in the long and the short tube, for we know that liquids find their own level. If a hole were made in the closed end of the tube this would immediately happen. There will be no difficulty, from what has been already said, in understanding that the column of mercury is kept in its position by the weight of the atmosphere pressing upon the surface of the mercury in the short open tube. The weight of the column of mercury and the weight of a column of the atmosphere with the same sectional area is exactly the same ; both being measured from the level of the mercury in the short

stem of the barometer shown in Fig. 95, the mercury column to its upper limit in the long tube, the air to its upper limit, which as will be seen, is a great distance from the surface of the earth. If for any reason the weight of the atmosphere becomes greater, the mercury will be pushed higher to preserve the balance; if it should become less, then similarly the amount of mercury which can be supported will be less, and so the height of the column of mercury is diminished.

The student will now understand why it is so necessary to remove all the air bubbles in Expt. 193. If this were not done, when the tube was inverted the enclosed air would rise through the mercury and take up a position in the top of the tube above the mercury. The reading would not then be thirty inches, for instead of measuring the whole pressure of the atmosphere, what we should really be measuring would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the tube. In a properly constructed barometer, therefore, there is nothing above the mercury in the tube except a little mercury vapour.

An arrangement like that described constitutes a *barometer, which we can define as an instrument for measuring the pressure exerted by the atmosphere.*

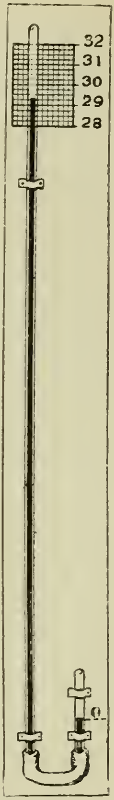

FIG. 95.—To explain the Principle of the Barometer.

§ EXPT. 194.—Procure a thick glass tube about thirty-six inches long and closed at one end. Fill the tube with mercury; place your thumb over the open end; invert the tube; place the open end in a cup of mercury and take away your thumb. A column of mercury will be supported in the tube by the pressure of the atmosphere. The distance between the top of the column and the surface of the mercury in the cup will be about thirty inches.

§ EXPT. 195.—Weigh the column of mercury sustained in the barometer

tube and measure the diameter of the tube. The area of the bore can then be found (area of circle = radius $^2 \times 3\frac{1}{7}$). Calculate from these observations the weight of a column of air on any given area.

If the tube had an area of exactly one inch, there would be thirty cubic inches of mercury in a column thirty inches long; and since a cubic inch of mercury weighs about half a pound, the whole column would weigh fifteen pounds. This column balances a column of air of the same area, so that we find that the weight of a column of air upon an area of one inch is fifteen pounds when the barometer stands at thirty inches.

Barometers as Weather Glasses.—The only direct measurement we can make with the barometer is that of the weight of the atmosphere. Since, however, this weight is influenced by a variety of circumstances which affect the weather, these variations of the atmosphere's weight can supply information respecting the probable weather conditions. If the atmosphere is warm and ladened with moisture, it is lighter bulk for bulk than a cold dry specimen would be. The prevalent south-west winds which so influence the climate of these islands affect the upper regions of the atmosphere, warming them and saturating them with moisture, before we become aware of their arrival on the surface, by the weather changes they produce. But the whole extent of the atmosphere influences the height of the barometer, and consequently the changes brought about high up in the air, though they cause no change in the weather, do produce a difference in the weight of the atmosphere, lightening it, and causing the barometer to sink. Soon after come the corresponding weather changes, which are evidently, then, later results of the same cause as brought about the change in the barometer reading. The barometer thus indicates what the weather is likely to be. From considerations such as these applied to many other circumstances than that we have described, meteorologists have been able to construct the following table,[1] showing the probable weather which will accompany certain weights of the atmosphere.

Height.	State of the weather.
31 inches	Very dry
$30\frac{2}{3}$,,	Settled weather
$30\frac{1}{3}$,,	Fine weather

[1] From Ganot's *Physics*, translated by Prof. Atkinson.

Height.	State of the weather.
30 inches	Variable
$29\frac{2}{3}$,,	Rain or wind
$29\frac{1}{3}$,,	Much rain
29 ,,	Tempest.

Why Mercury is used for Barometers.—The use of mercury for barometers is a matter of convenience. Since the column of mercury which the atmosphere is able to support is 30 inches high, it is clear that, as water, *e.g.*, is 13·6 times as light as mercury, the column of water which could be supported would be $30 \times 13{\cdot}6 = 408$ inches = 34 feet, which would not be a convenient length for a barometer. The length of the column of glycerine which can be similarly supported is 27 feet. But in the case of lighter liquids like these, any small variation in the weight of the atmosphere is accompanied with a much greater alteration in the level of the column of liquid, and in consequence it is possible to measure such variations with much greater accuracy. For this reason barometers are sometimes made of glycerine. There is one in the Western Galleries of the South Kensington Museum, which the student could see at any time. Several of the reasons which make mercury such a suitable liquid for a thermometer, and which the student has already learnt, apply also to its use in barometers.

Pressure of the Atmosphere at Different Altitudes.—The atmosphere being a material substance, the longer the column of it there is above the barometer, the greater will be the weight of that column, and the greater the pressure it will exert upon the mercury in the barometer. Hence, as we ascend through the atmosphere with a barometer, we reduce the amount of air above it pressing down upon it, and in consequence the column of mercury the air is able to support will be less and less as we ascend. On the contrary, if we can descend from any position, *e.g.*, down the shaft of a mine, the mercury column will be pushed higher and higher as we gradually increase the length of the column of air above it. Since the height of the column of mercury varies thus with the position of the barometer, it is clear that the variation in its readings supplies a ready means of ascertaining the height of the place of observation above the sea-level, provided we know the rate at which the height of the barometer varies with an alteration in the altitude of the place.

The rule which expresses this relation is not a simple one, but for small elevations it is said that a rise or fall of one inch in the height of the barometer corresponds to an alteration of 900 feet in the altitude of the barometer.

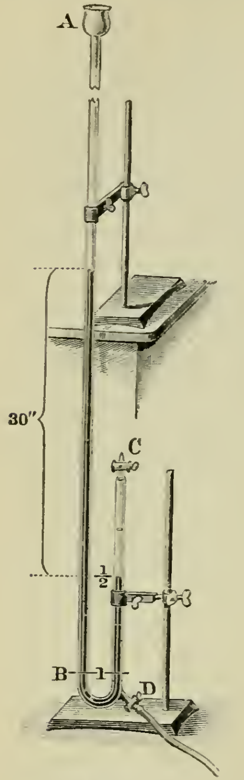

FIG. 96.—Apparatus for proving Boyle's Law.

Pressure of Atmosphere at Different Altitudes.—Boyle's Law.—Before we can properly understand how and why the density of the atmosphere varies, it is necessary to become acquainted with the rule expressing the relation between the volume and pressure of a gas.

EXPT. 196.—Take a piece of barometer tubing and bend it into the shape of the barometer which we have already described. Close the short limb and leave the other open. Or procure an apparatus similar to that shown in Fig. 96. Pour in a little mercury so as to close the bend and arrange matters so that the mercury stands at the same level in each limb. In the case of the second arrangement this is done by opening the stopcock C during this stage of the experiment and then closing it. We have enclosed a given volume of air, which must be measured by noticing its length. It is subjected only to the pressure of the atmosphere. Pour mercury down the longer limb until the difference between its level in both limbs is equal to thirty inches, or whatever is the reading of the barometer at the time of the experiment. Measure the length of the air column which is now subjected to a pressure equal to two atmospheres, and notice that it is one-half of the original volume. That is, by doubling the pressure we have halved the volume.

Add successive amounts of mercury, and when the apparatus has cooled down measure the difference in the levels of the mercury in the two tubes and also the length of the air column. If we

multiply the total pressure (obtained by adding the height of the barometer to the difference in level of the mercury in the two tubes) by the volume of the air we shall notice that the result is always the same. This relation was discovered by Boyle, and is known as *Boyle's Law.* It can be expressed by saying *that when the temperature remains the same, the volume of a gas varies inversely as its pressure.* Or, what is the same thing, *the temperature remaining the same, the product of the pressure into the volume is constant.*

But it has been learnt that if we increase the volume occupied by a given mass of a substance we decrease its density, or if we decrease its volume we increase its density. Therefore, we not only decrease the volume of the enclosed air in the above experiment, but we increase its density. The increase of density and the increase of pressure are proportional to one another. It is not difficult to apply these facts to the case of the atmosphere. We have learnt that the pressure of the atmosphere decreases as we ascend, and we are now able to add that its density decreases also and at the same rate. Therefore the densest atmosphere will be that at the surface of the earth, leaving out, of course, the air of mines and other cavities below the surface, where the air will be denser still. The air gets less dense or rarer as we leave the surface, until eventually it becomes so rare that its existence is practically not discernible.

Height of the Atmosphere.—The results which have been obtained are interesting. Thus, Mont Blanc is not quite three miles high, and the height of the barometer there is only about fifteen inches instead of the thirty at the sea-level; therefore, the pressure of the atmosphere is only one-half, and the density is consequently one-half, or a cubic foot of air, instead of weighing one and a quarter ounces, would weigh five-eighths of an ounce. The highest point ever reached by balloonists up to the present is something over seven miles, by Messrs. Coxwell and Glaisher in 1862, and the atmosphere was there so rare that they were unable to breathe properly and became unconscious. But there are other ways in which the presence of the atmosphere can be demonstrated at much greater distances from the earth's surface. Bearing in mind that light is refracted or bent on passing from a rarer into a denser medium, it will not be difficult to understand that the sun always appears

higher in the heavens than it really is, for in Fig. 98, when the sun appears to an observer at A to be rising at S′ it is really at S below the horizon. If it appears to be at S″, and therefore setting, to an observer at B, it really has set at some previous moment. Thus, even after the image of the sun is no longer visible, rays of light reach the observer because of this refracting power of the atmosphere. It is possible from these considerations, causing the phenomenon of *twilight* before

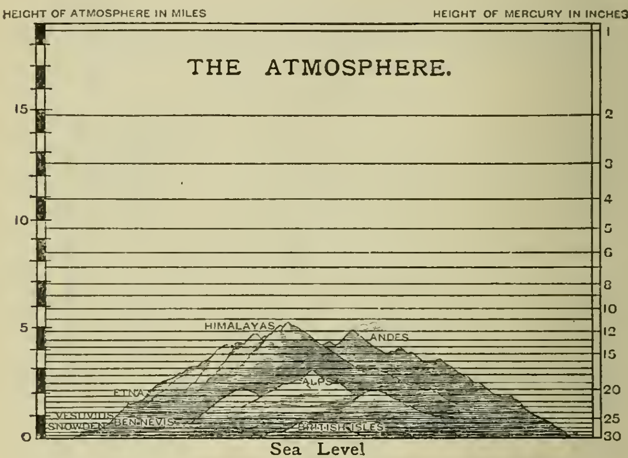

FIG. 97.—To show the height of the Barometer at different altitudes.

sunrise and after sunset, to demonstrate the presence of air at a distance of forty-five miles from the earth's surface.

The phenomena of meteors or shooting stars also provide the astronomer a means of proving the existence of air at still greater heights. These meteors become luminous by the heat developed in consequence of the friction between the meteor and the air particles. The absence of air means the development of no heat of friction, and as a necessity the emission of no light waves. Just as soon as the meteor can be seen, therefore, we know it has begun to collide with air particles or to have entered the earth's atmosphere, and a measurement of this distance from

the earth, which has been found to be about 200 miles, gives the extent of an atmosphere of sufficient density to bring about these results.

Since the density of the air gradually diminishes, and there is no reason why this process should not go on indefinitely, there is no point at which the earth's atmosphere can be said to terminate. It will become rarer and rarer by such insensible degrees, the distance between the particles will so gradually increase, that it will only be at a very great height indeed that one can fairly say there is no air, and even then all that would be meant would be that the distance between the particles is so enormously great that for all practical purposes air is non-existent.

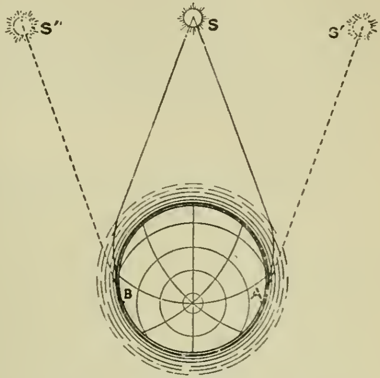

FIG. 98.—To show how Atmospheric Refraction causes the Sun to be visible when below the horizon S at A and B.

Diffusion of Gases.—Before dealing with the composition of the atmosphere, it will be desirable to briefly describe the manner in which gases mix with one another, since one of the first things we shall find about the air is that it is a mixture of certain gaseous substances. It is a matter of common observation that if a bottle of some evil-smelling gas, such as sulphuretted hydrogen, for instance, be opened and placed upon the table in the middle of a room, it will not be many minutes before it can be smelt in every part of the room. Moreover, if we examine the contents of the bottle after this lapse of time, we shall find that it will no longer burn when a lighted taper is put to it as a bottle of sulphuretted hydrogen will do. Evidently, then, the noxious gas in the bottle has spread itself throughout the room according to what we have seen is a natural tendency of all gases to fill as much space as possible. This has been brought about by the *diffusion* of the sulphuretted hydrogen.

We can define diffusion as the tendency possessed by the molecules of gases to separate themselves as much as possible. We can, however, form the best mental picture of what the process of diffusion is if we have some

idea of the *Kinetic Theory of Gases.* On this hypothesis the molecules of which a gas is composed are in continual rapid motion. Considering one molecule alone—for a great part of its path it travels forward in a straight line, there being no force acting upon it. If it comes into contact with another molecule, being perfectly elastic as is supposed, the only thing which happens to it is that it gets its direction of motion exactly reversed but its velocity remains unaltered. The pressure which the gas exerts upon the sides of the containing vessel is due to the force of impact of the incessant battering of these molecules. The pressure of the gas increases with an increase of temperature because such a rise of temperature causes the molecules to move with a greater velocity and in consequence to come into contact with the sides of the vessel more often.

If we conceive the molecules endowed with this rapid velocity, it is easy to understand the phenomena of diffusion which follow. If we fill a jar of hydrogen in the manner already described over water (p. 119) and cover its mouth with a glass and similarly fill another jar of the same size with oxygen and then place the jar of hydrogen over the jar of oxygen and remove the glass plates, it will be found after two or three seconds that both jars are full of an explosive mixture, showing that the two gases have intimately mixed or diffused into one another. The heavier oxygen has diffused upwards and the lighter hydrogen downwards. The molecules of oxygen travelling with an enormous velocity having reached the limit of their own jar, continue their journey up into the hydrogen until stopped either by another molecule of hydrogen or by the sides of the jar, and similarly with the molecules of hydrogen in a downward direction.

Composition of the Air by Volume.—We have already learnt from Expt. 135 that the air is almost entirely composed of oxygen and nitrogen. In that experiment the burning phosphorus combined with all the oxygen and left the nitrogen, which was found to measure about four-fifths of the volume of the air, filling that part of the bell-jar above the water. To accurately determine the composition of air by volume we proceed in a similar manner to that adopted in finding the composition of water by volume synthetically (p. 125). The eudiometer is first filled with mercury, and then a convenient amount of the air we wish to analyse is bubbled in. Making use of the rough relation between the volumes of oxygen and nitrogen which we have already learnt, we then bubble in more than enough pure dry hydrogen to form water with the oxygen present in the volume of air taken. Using the precautions mentioned in the experiment above referred to, we pass an electric spark. All the oxygen present combines with a part of the hydrogen introduced,

forming water which condenses as the apparatus cools. It is thus easy to measure the amount of diminution in volume, and as the student knows, one-third of this diminution gives us the exact measure of the volume of oxygen present in the amount of air taken. The difference between the volume of oxygen thus found and that of the air taken will give the amount of nitrogen present in the atmosphere, supposing we neglect the small amounts of certain other substances which are present. The result of a series of such experiments gives the following composition of the air by volume :—

Oxygen . . .	20·96
Nitrogen . .	79·04
	100·00

A result almost exactly the same as this is obtained from whatever place we obtain the specimen of air or at whatever season of the year it is collected.

Composition of the Air by Weight.—The method which is adopted in this determination depends upon the fact that if air be passed over strongly-heated copper, this metal combines with the oxygen, forming a black oxide of copper, while the nitrogen passes on, and can be collected and weighed. To perform the experiment the air must be first freed from the small quantities of other substances present, to which reference has been made, by passing it through suitable materials which will remove them. A known volume of it is then passed over a weighed amount of copper heated to redness, and the nitrogen is collected in an exhausted receiver whose weight is also known. The increase in weight of the copper gives the amount of oxygen, the increase in that of the receiver the quantity of nitrogen present in the mass of air taken.

The result of several experiments conducted on this plan gives the composition of air by weight as :—

Oxygen . . .	23·005
Nitrogen[1] . .	76·995
	100·000

[1] Recent work has shown that about one per cent. of this nitrogen is really a new element, to which the name Argon has been given.

Other Substances present in the Air.—In addition to oxygen and nitrogen there are other substances present in the air in small quantities which vary in amount according to different circumstances. Thus there is always some *water vapour* derived from the surfaces of the various bodies of water in different parts of the earth. This amount depends upon the temperature chiefly, and we shall have to consider its formation more fully later. The actual amount present can be ascertained in a manner to be immediately described. There is also always *carbon dioxide* present in amounts varying from ·037 to ·062 in 100 parts of air. This, it has been learnt, is the product of the combustion of carbon in oxygen, which may take place either in the bodies of animals, or in ordinary cases of burning which are familiar to every one. Of course, the percentage of this gas will be greatest in large towns and least in the open country far removed from civilisation. Then *ammonia* is found, generally in minute quantities, in any sample of air which is examined, as well as *ozone* and the *oxy-acids of nitrogen*, both of which are probably the result of electric discharges in the atmosphere.

In the manufacturing districts of this country traces of *sulphur dioxide* or *sulphuric acid* are very common and certain other things in even smaller amounts.

Animal and Vegetable Life in Relation to the Atmosphere.—The question will suggest itself, How is it that, if carbon dioxide is continually being added to the atmosphere in so many ways, its percentage does not steadily increase? The answer is to be found in a consideration of the work done by green plants. The greenness of plants is due to the presence in the leaves, and other similarly coloured parts, of a somewhat complex compound known as *chlorophyll*, which has the power, in bright sunlight, of decomposing carbon dioxide, eliminating the oxygen and retaining the carbon, which combines with the elements of water in the leaf, forming a compound known as *starch*. Under the influence of a peculiar ferment in the plant cell, the starch is changed into a compound with a very similar chemical composition known as sugar, but differing from it in the very important respect of being soluble in the sap, while the starch is insoluble. The sap circulates throughout the plant, providing the growing parts with nutriment and enabling it to increase in size. Any excess of nutritive material in the form of sugar or other soluble

compound is in certain parts of the plant reconverted into starch, or some other reserve material, which will at some future time provide nutriment when there is no chlorophyll to manufacture it.

It becomes clear in view of these considerations why the amount of carbon dioxide does not increase in the air, it is being as persistently broken up as it is being added. A wonderful balance is kept up. The animal creation continually breathe out carbon dioxide the carbon of which is as regularly assimilated by the plants, while the oxygen again becomes available for the maintenance of the animal's existence. The animal and vegetable kingdoms are thus dependent the one upon another. It should be noticed in passing that the chlorophyll in the presence of sunlight does work, it decomposes the carbon dioxide and further builds up the substance of the plant in the way we have described. Energy is in this way stored up in the tissues of the plant, which therefore represent so much potential energy which, when the vegetable material is used as a combustible, becomes again kinetic.

§ EXPT. 197.—Grow mustard and cress seeds on wet flannel, or suspend beans or acorns in a bottle of water to show that plants are built up from materials which exist in the atmosphere.

The Air is a Mixture of Gases.—Chemists have decided that the air is a mixture and not a chemical compound. They have arrived at this conclusion for several reasons, which include the following :—

1. The composition of a chemical compound never varies (p. 110), while that of the air does vary slightly. Further, if oxygen and nitrogen be mixed in the proportions in which we have learnt they are generally present in the atmosphere, the mixture acts just like air does.

2. Whenever a chemical compound is formed it has been found that a certain amount of heat is developed depending upon the compound. When oxygen and nitrogen are mixed as described above there is no evolution of heat.

3. The proportion in which oxygen and nitrogen are mixed in the air does not bear any simple relation to the combining weights of these elements, while in the case of every chemical compound such a relation does exist, the amounts of the elements present always being some multiple of the combining weights.

4. Whenever a gaseous chemical compound which is soluble in water is shaken up with this liquid, and after being dissolved is again

expelled, it is found to have undergone no change in composition. In the case of water this is not so, as the following table shows : —

	Air undissolved in water.	Air dissolved in water.[1]
Oxygen	20·96	33·64
Nitrogen	79·04	66·36
	100·00	100·00

The Pressure of the Air varies in the same Place.—That this is the case every one knows. If it were not so the reading of the barometer would always be the same in any place, and having once recorded the pressure there would be no further use for the barometer there. We must now consider the reason of this variation. It follows naturally from two things which have been already discussed. (1) An increase of temperature produces a diminution in the density of the atmosphere, and consequently a diminution of pressure, which is accompanied by a fall in the barometer. (2) Water vapour is lighter than air in the proportion of 9 to 14·5. Consequently if there is a large amount of water vapour present in the atmosphere at a place the pressure exerted by it will be less since the air is now lighter bulk for bulk.

Thus the rule will be that, other circumstances remaining the same, an increase of temperature is accompanied by a fall in the barometer, or where the thermometer is high the barometer is low. Similarly, with the same reservation, an increase of the amount of water vapour will cause a low barometer reading. We shall see later how this affects the readings of the barometer in different districts. In order to map out the pressure of the atmosphere in different parts of the world it is usual to draw lines through all those places which have the same barometer reading at any given time. Every morning, observers in the chief towns of this country, as well as those on the continent, telegraph the height of their barometers to a central office in London. These numbers being placed against their respective towns on a map, it is quite easy to join in those places where the reading is the same at the particular time of observation. Lines so obtained are called "equal pressure lines," or *isobars*. In the *Times* newspaper every morning there is a map of part of the south-

[1] See Roscoe and Lunt's *Chemistry for Beginners*, p. 135.

western portion of Europe with these isobars marked. Fig. 99 gives a reproduction of the map in the issue of August 2, 1895, where it will be seen that the isobars range in curves around a centre to the west of Scotland, and that the height of the barometer increases from the centre outwards.

METEOROLOGICAL REPORTS.
WEATHER CHART, FRIDAY, AUGUST 2, 6 P.M.

FIG. 99.—The *Times* Weather Chart.

How the Atmosphere is Warmed.—Some of the ether waves from the sun travelling through space come into contact with the earth's atmosphere. A small part of them are reflected from the outer surface of the atmosphere, but the greater part enter and are either transmitted to the earth or absorbed in their passage through the air. About one-third of the rays which enter the aërial envelope, and are capable of

P 2

being converted into heat energy, are absorbed in their passage, while the remaining two-thirds are transmitted, and reaching the surface of the earth are absorbed by it and warm it. At sunrise and sunset these rays have to pass through a greater thickness of atmosphere than at noon, consequently more of their heat is absorbed by the air (Fig. 100). The same bundle of noonday rays *bb* is also spread over the larger surfaces *aa* and *cc* at sunrise and sunset. The heated earth exerts a twofold influence upon the air in contact with it, first the air becomes warmed by the heat it receives from such contact, and secondly, since the earth continually radiates this heat again, the air becomes heated by these radiations also. The heat-rays which leave the earth in this second process are found to have undergone a complete change of character ; they are no longer luminous, but belong entirely to the kind of radiation we have called dark-heat waves. The atmosphere cannot transmit them as it could before, or using words which are generally employed in speaking of radiation, while the air is diathermanous to the luminous rays from the sun it is more or less athermanous to the dark radiations. A similar change is brought about in a more marked degree by glass, a fact which is made use of in the construction of greenhouses. It should now be clear to the student why the air nearest to the earth is warmest and why it is that as we ascend into the atmosphere the air becomes colder and colder. This difference in the amount of warmth with an increase of altitude is spoken of as the vertical distribution of temperature. The approximate rate of diminution of temperature is often given as 1° F. for every 300 feet of ascent. But it is by no means regular. There is a decrease, but not a regular one, for every 100 feet of ascent during the day up to 2,000 feet, and a small variable diminution in temperature on ascending at night up to something like the same height.

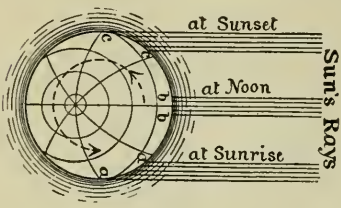

FIG. 100.—Showing the greater thickness of atmosphere passed through by the rays of the sun at sunset and sunrise than at noon.

Temperature of the Atmosphere.—We have now to consider how the temperature of the air at the earth's surface varies from place to place, and to see what circumstances affect the temperature of any given locality. It is the water vapour in the atmosphere which causes most of the absorption of heat such as has been described. The larger the amount of water vapour the greater the amount of heat absorbed ; and clearly the greater the thickness of atmosphere which the rays have to traverse, the larger will be the amount of heat which is prevented from passing. Those circumstances, therefore, which affect these conditions will influence the temperature of the place. As has been already learnt, the altitude of the sun varies in different latitudes. The more nearly vertically the rays from the sun strike the earth, the less will be the extent of atmosphere traversed, and the larger the amount of heat radiation which reaches this planet. As the student knows, the sun is most nearly vertical in equatorial regions and it is there most heat will be received, this amount getting smaller as the poles are approached.

Isotherms.—If we imagine lines drawn round the earth through those places which have the same temperature at any given time, we shall be able to form an idea of the *horizontal distribution of temperature* or the distribution of temperature on the earth's surface. Such lines are called "lines of equal temperature," or *isotherms*. Across the oceans isothermal lines are roughly parallel to the lines of latitude, whereas over the land areas their course is more devious. This is what would be naturally expected from what has been said of the properties of water. Its high and uniform specific heat causes it to be warmed regularly, and though it requires a large amount of heat to warm it, yet it loses its heat with the same difficulty. The crust of the earth, on the other hand, is made up of different materials, with varying specific heats and diverse degrees of conducting power, and these will consequently be warmed to different extents and the contiguous atmosphere will participate in the same variations. The isotherms will thus curve about and show the same vagaries as the superficial temperature. In January the temperatue of the superficial air between the equator and the parallel of latitude 20° S. is 80° F. ; while in July this temperature is experienced over a greater area extending from the equator to 20° N. latitude, as far as the oceans are concerned.

but on the land reaching and crossing 40° N. latitude. Moreover, in July the temperature 90° F. is reached in the area, including the Sahara Desert, Arabia, and neighbouring countries, through which the parallel of latitude 20° N. passes. This is the natural result from what we have said about the variation of seasons in the two hemispheres. In January it is winter in the northern and summer in the southern hemisphere, and the sun is vertical over the Tropic of Capricorn, or latitude $23\frac{1}{2}°$ S. In July the conditions are reversed. The other isothermal lines, during these two months, undergo the same kind of movement as a consequence of the apparent movement of the sun.

Chief Points of Chapter XIII.

Determination of the Weight of Air.—This is done by weighing a stoppered flask (1) full of air, (2) after the air has been driven out. The difference of weight is the weight of the air which filled the flask.

Pressure of Air.—In consequence of its weight, air exerts pressure. On the earth's surface, under ordinary conditions, the pressure of the atmosphere equals 15 lbs. per square inch.

The Height of the Atmosphere is determined (1) by observations of the duration of dawn and twilight, (2) by observations of meteors.

Boyle's Law applied to the Atmosphere.—When the temperature remains the same, the volume of a gas varies inversely as the pressure. If a cubic foot of air at sea-level, where the pressure is 15 lbs. per square inch, were taken up to a height of $3\frac{1}{2}$ miles, where the pressure is one-half, viz., $7\frac{1}{2}$ lbs. per square inch, it would expand to two cubic feet.

A Barometer is an instrument used to measure the pressure of the atmosphere.

The Principle of the Action of a Mercurial Barometer.—The column of mercury balances a column of air extending from the surface of the mercury in the cup to the limits of the atmosphere. The action is therefore analogous to balancing columns of different liquids in a U-tube.

Some Points referring to Barometers.—(1) Mercury is the liquid usually employed because it is the heaviest liquid known, is not very volatile, is easy to see, and does not wet the tube. (2) Water and other liquids can be used in the construction of barometers, but these barometers require to be longer in order to hold the longer liquid columns required to balance the atmospheric pressure. (3) If a crack or a hole is made in the top of a barometer, air enters through it, and the mercury column falls to the level of the liquid in the cup. (4) The height of the column of mercury is about thirty inches at sea-level, but

it varies from time to time on account of variations of atmospheric pressure.

Atmospheric Condition.	*Effect on Weight of Air.*	*Effect on Height of Barometer.*
Warm and Moist	Lighter	Falls
Cold and Dry	Heavier	Rises.

Pressure of the Atmosphere at Different Altitudes.—

Altitude.	*Height of Barometer.*	*Pressure in lbs. per sq. in.*
Sea-level	30 inches	15
$3\frac{1}{2}$ miles	15 ,,	$7\frac{1}{2}$

Diffusion is the tendency possessed by the molecules of gases to separate from one another as much as possible ; it is on account of this property that the gases in the atmosphere are so intimately mixed.

Composition of the Atmosphere.—

		By volume	By weight
Oxygen	...	20·96	23·005
Nitrogen	...	79·04	76·995
		100·00	100·000

Other substances present in varying proportions : water vapour, carbon dioxide, ammonia, ozone, argon, sulphur dioxide, dust particles.

Animal and Vegetable Life in Relation to the Atmosphere.—

Animals	breathe out	Carbon dioxide	which is absorbed by	Plants	and broken up into
Carbon,	which helps to build up the substance of plants	and	Oxygen,	which again becomes available for animals to breathe.	

Isobars are lines connecting places where the barometric pressure is the same.

The Manner in which the Atmosphere is Warmed.—(1) Part of the sun's rays is absorbed in passing through the atmosphere, and converted into heat. (2) The remainder goes to warm the earth, which heats the air in contact with it and radiates dark-heat rays which are absorbed by the atmosphere.

It is Colder as we Ascend because—(1) The air is above the general level of the earth, and therefore does not receive much heat by contact. (2) The air is rarefied and there is not so much above us to prevent the escape of heat radiated from the earth.

Isotherms are lines connecting places which have the same temperature at any given time.

Questions on Chapter XIII.

(1) Given a glass tube, thirty-two inches long, closed at one end, a bottle of mercury (quicksilver), and a small cup. State how you proceed (*a*) to construct a barometer, and (*b*) to show the readings of this barometer. (1896.)

(2) (*a*) State the average height of the mercury in a barometer at the sea-level and at the top of a mountain three and a half miles high.

(*b*) What is the cause of the difference in the height of the mercury column?

(*c*) What do you know concerning the height to which the atmosphere extends?

(*d*) What do you know concerning the condition of the upper layers of the atmosphere? (1895.)

(3) (*a*) How can it be proved that the air has weight?

(*b*) In what proportions and in what condition are oxygen and nitrogen present in the air?

(*c*) Describe experiments by which oxygen can be taken out of air and collected in a separate vessel.

(*d*) Describe an experiment by which nitrogen may be separated from the oxygen in the air. (1894.)

(4) (*a*) Why does the mercury stand higher in the tube than in the cup of a barometer?

(*b*) What is the average height of the mercury in a barometer tube at the sea-level?

(*c*) Why does the height vary from time to time?

(*d*) Why is the barometer regarded as a "weather-glass"? (1893.)

(5) If you ascended to the height of $3\frac{1}{2}$ miles in a balloon, carrying a barometer and a thermometer, state—

(*a*) The indication which would be given by the barometer.

(*b*) Your explanation of this.

(*c*) The indication which would be given by the thermometer.

(*d*) Your explanation of this. (1892.)

(6) State the principle on which the action of a mercurial barometer depends. Why is a water barometer longer than a mercurial barometer? What occupies the space above the mercurial column in the latter instrument? If a hole were to be bored through the glass above the column of mercury, what would happen? (1891.)

7. Explain the chief reasons why mercury is the liquid usually employed in the construction of—

(*a*) Barometers.

(*b*) Thermometers. (1889.)

(8) How can the weight of air be determined? In what way is the pressure exercised by the atmosphere on the earth's surface, in consequence of its weight, stated? How is it that we are able to move about under the weight of the atmosphere? (1889.)

CHAPTER XIV

ATMOSPHERIC PHENOMENA

Condensation of Water Vapour.—It has been seen that air always contains a certain amount of water vapour. The actual quantity present depends upon the temperature of the atmosphere. Consequently there will be more in summer than in winter, although if we were to judge only by our feelings we should say the air was drier during the former season. The sensation of dryness results from the fact that the air could take up considerably more water vapour than there is in it, since it is at this higher temperature. If we compare the amount of water vapour actually present with the maximum quantity it could take up at a given temperature, we should have a measure of what is known as the *hygrometric state* of the air at the time of the experiment. The hygrometric state or degree of saturation of the air is ascertained by the use of an instrument called a *hygrometer*. There are many kinds of hygrometers.

By passing a known volume of air through some substance which has the power to remove all the moisture from it, such as calcium chloride or strong sulphuric acid, and noticing how much the dehydrating agent, as it is called, has increased in weight, we obtain a very accurate form of hygrometer, known as the *chemical hygrometer*.

A more usual plan, however, is to use a form of instrument known as *Mason's Hygrometer*. It consists of two precisely similar thermometers, suitably attached to a board as in Fig. 101. Round the bulb of one of the thermometers is tied a piece of muslin to which cotton threads are attached and which hang down into water kept in a glass which is supported as shown in the figure. The instrument depends for its use upon two facts which have been already brought before the student's attention. The first is that water is only vaporised at the

expense of a certain amount of heat, and secondly, the quantity of water vapour which air can take up at any temperature depends upon the amount already contained by it. Water rises up the cotton threads by the force known as capillary attraction and consequently keeps the muslin moist. The water on the muslin evaporates, getting the heat necessary for evaporation from the bulb of the thermometer which it surrounds. The thermometer is thereby cooled and the column of mercury sinks. This continues until the air round the bulb is saturated and evaporation ceases. Thus the wet-bulb thermometer records a lower temperature than the one with a dry-bulb. The difference between the readings is greater the drier the air was at the commencement of the observation, and we have a means of estimating the amount of water-vapour present by seeing how much more must be added to saturate it.

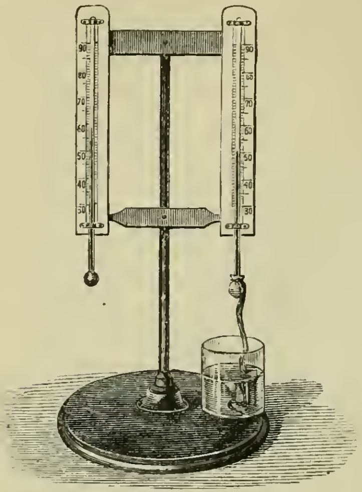

FIG. 101.—Mason's Hygrometer.

The Water-Vapour in the Air sometimes becomes visible, assuming one of a variety of different forms according to the circumstances bringing about the necessary condensation. Some of the commonest products of this condensation are *fog*, *mist*, *clouds*, *rain*, *snow*, *hail*, *dew*, *hoar-frost.* We shall give a short account of each of these phenomena, and since they are all results of the conversion of the water vapour either into liquid or solid water, it will be desirable to refer briefly to the conditions which result in such condensation.

Evidently condensation and evaporation are exactly opposite processes. Since the absorption of heat is necessary for the conversion of a liquid into a gas, there will be an evolution or development of heat when the contrary change, from the gaseous to the liquid condition, is effected or when the gas is condensed.

Any process which results in the cooling of a mass of air will cause some water-vapour to assume one of the states we have enumerated, and all the circumstances of which we shall have to speak are really methods of bringing about such a lowering of temperature.

Mists and Fogs.—The general features of those forms of condensed moisture which are referred to under these names are familiar to every one. We naturally associate mists with rivers or other water surfaces; most often they make their appearance after the sun has set. They seem to be caused in this way; the air over the land by the side of the river gets cold more quickly than that over the river itself, because land radiates heat very much better than water does. The air over the water will show a tendency to rise, and the cold air will move towards the water to take its place. But the air over the water will thus be cooled and will be unable to hold as much water-vapour as before, and the excess of moisture assumes the nature of a mist. It is impossible to say when a mist becomes a fog. A fog is generally regarded as something denser and blacker than a mist. The condensation which forms a fog at all events, and probably a mist also, takes place round the small particles of dust in the air, which act as nuclei for the minute water drops which make up the fog. In London or the large manufacturing towns, where there is so much carbon in the air, the fogs become very bad indeed—or, as is commonly said in the former place, they are thick enough "to cut."

Some localities are rarely free from fog, since the permanent conditions are so exactly suited to its formation. We have almost perpetual mists and fogs, for example, along the coast of Newfoundland, where the air above the warm Gulf Stream, ladened as it is with moisture, comes into contact with the air over the cold Labrador current. Just as a fog is caused by a lowering of the temperature of the air, so if the temperature again becomes raised by any means the fog will disappear. It is in this way that the mists are cleared away by the heat of the sun as it rises higher and higher in the heavens.

It is a very common experience in the ascent of a mountain that mists are encountered as soon as the height attained becomes only a few hundred feet. The lowering of temperature which here causes the mist is the result of the cooling of the air as it

was forced up the side of the hill by, it may be, the impact of a wind with the mountain or some similar cause.

Clouds.—Clouds are formed in a manner precisely similar to mists and fogs. They differ only in their position, and can be very correctly regarded as fogs high up in the air. When from any cause an upward current of warm air ladened with invisible moisture is cooled in these higher atmospheric regions, a cloud will be produced. This can be brought about by a warm, moist stratum coming into contact with a cold current of air, whereby it becomes cooled and some of its moisture is condensed into minute particles, which the late Prof. Tyndall called "water-dust." Or, in its upward passage, as we have learnt in considering the vertical distribution of temperature in the atmosphere, it naturally comes to a colder zone, and as naturally some of its moisture takes the visible form of a cloud, while that below it in the warmer belts of air remains invisible. The forms assumed by clouds are endless in their variety. It is only necessary to watch the ever-changing shapes they assume during a short period of a breezy summer day to become charmed with their beauty and impressed by their grandeur. Yet in this shifting panorama some order has been detected resulting in a *classification of clouds.*

There are said to be three original forms from which all others are derived by combinations, in varying amounts, of these simpler shapes; they are—(1) *Cirrus* or curl cloud; (2) *Cumulus* or summer cloud; (3) *Stratus* or continuous sheets of cloud. If a cloud shows some of the characters of the first and third of these, for instance, it is referred to as a *cirro-stratus;* similarly *cumulo-stratus*, *cirro-cumulus*, *cumulo-cirro-stratus*, and other forms of clouds are distinguished. The last of the combinations we have just given is more often spoken of as *nimbus* or a rain-cloud. The particular form assumed by the condensed moisture will depend upon a variety of conditions, the chief of which are the height of the cloud and the amount of movement there is in the air at the time. Before leaving the subject of clouds it should be pointed out there are good reasons for believing that some of the particles constituting a cloud are in the solid condition in the form of minute particles of ice. This is most probably the case in those very lofty feathery clouds which we have spoken of as cirrus clouds, since when such clouds come between the observer and the sun or moon a halo is produced.

Rain.—The particles constituting a cloud, that is, the water dust spoken of above, continually tend to coalesce or unite together to form larger drops. When these reach a certain size

the air can no longer support them and in consequence of their increased mass they fall, being more strongly attracted to the earth. They do not always reach the surface of the earth, however, for in their downward course it may happen that they have to traverse a layer of dry, unsaturated air, when the drops will become wholly evaporated again. In their passage through very moist air, then, rain-drops continually get larger, whereas in falling through dry air they become smaller until they may even eventually disappear.

Snow.—Sometimes the temperature of a cloud is below the freezing-point of water, when it is manifestly impossible for the moisture to assume the liquid state, and it becomes condensed in a solid form. If, in addition to this, the temperature of the air through which the descending solid particles pass is below the freezing-point, we shall have a fall of solid particles in the form of *snow*. The falling particles unite continually to build up larger masses which we know as *snow-flakes*, which, under favourable conditions, assume the most beautiful forms. Ice crystallises in the system called the *hexagonal*, and it is found on examining snow-flakes that they are combinations of minute crystals belonging to this system. Their shapes are seen to perfection in the Arctic regions, and observers in these high latitudes have recognised over a thousand different forms. In this country they will be best seen when a fall of snow takes place in a still, quiet atmosphere, with the temperature at zero or lower to prevent a partial thaw ruining their exquisite beauty. If the snow in its descent upon the earth becomes partly melted, and perhaps later on partly frozen again, instead of snow-flakes reaching the surface we shall have a mixture of half-melted snow and rain, which is called *sleet*.

FIG. 102.—Snow-Flakes.

When the temperature of the atmosphere at the surface of

the earth is never as low as the freezing-point, snow cannot fall, for it will be melted before reaching the earth. Such a condition of things obtains within the tropics and extends to a distance of about 30° N.; while south of the equator, the limit is farther removed from the equator towards the Antarctic regions.

In high latitudes the average temperature is always below the freezing-point and snow exists on the ground all the year round. *That level, in any latitude, above which snow is always found is*

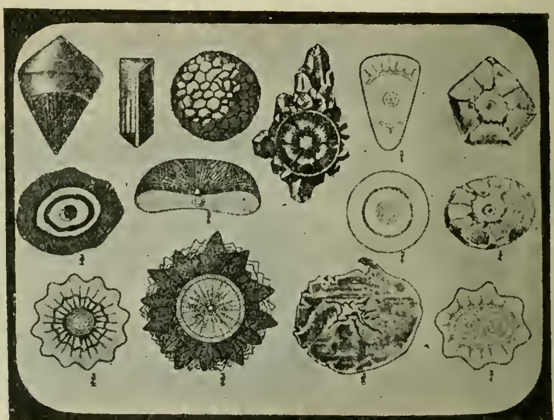

FIG. 103.—Hail-stones, and Sections of them.
From Gregory's Physiography Slides (George Philip and Son).

called the snow-line. This line touches the surface near the poles and attains its highest elevation in the tropics, never getting nearer than about 13,000 feet to the sea-level.

Hail.—The mode of formation of hail-stones has never been satisfactorily explained. In our country it falls more commonly in summer and spring than during the winter months. Its existence seems in some way to be connected with the electrical state of the atmosphere. It has been suggested that it is quite sufficient to imagine a very cold current of air impinging against a moist cloud, and suddenly lowering its temperature as a whole

to below the freezing-point, to account for its formation. However it may be formed, it is another instance of the condensation of atmospheric vapour in the solid state. Hail-stones take the form either of hard or soft pellets which vary in size from a small pea to a small hen's egg. Just as rain-drops and snow-flakes commonly increase in size as they approach the earth's surface, so do hail-stones aggregate together in their downward flight, becoming larger and larger as they reach their destination. An examination of hail-stones at different times and in various places has shown that they vary in their nature. Sometimes, on cutting through a hail-stone, it is seen to be built up round a speck of dust as a nucleus and to take the appearance of having been gradually built up, and not formed *en masse*, exhibiting, as it does, a more or less stratified structure. Soft hail-stones seem to be small lumps of snow without any central dust particle.

Dew.—Dew differs from the forms of condensed moisture as yet described in being formed *upon* the surface of the earth. After sunset, the surface of the earth, which has been receiving heat throughout the day, begins to radiate this heat in the manner already described. Different parts of the earth possess differing powers of radiation. Those which during the day absorb heat to the greatest extent radiate it most abundantly after the sun has disappeared and consequently become cooled down before those whose radiating power is small. Similarly, the air in contact with these bodies also becomes cooled down and is then unable, as we have seen, to hold as much water vapour as before and the surplus is deposited in the form of *dew*. The temperature at which this deposition begins is called the *dew-point*.

§ EXPT. 197.—Illustrate formation of dew by bringing a glass of cold water into a warm room.

For an abundant formation of dew several conditions are necessary. First, radiation must go on freely, and this happens on *bright clear evenings* when there are no clouds to obstruct the radiation. The air which is being cooled by contact with the body from which free radiation is taking place must not be disturbed before the dew-point is reached or no dew will be thrown down, that is, the *evening must be still*. A breeze will constantly renew the air above the body which is being cooled

by radiation and will prevent the dew-point being reached. The best radiating surfaces are those of leaves, whether of grass or other plants, also stones and similar things.

Side by side with this simple condition of things, Mr. Aitken has shown that another process is going on which considerably augments the amount of dew formed. Throughout their life, plants continually give off water in the form of vapour, which is exhaled through the numerous apertures spread over their leaves, especially the under surfaces. This process, which is known as *transpiration*, supplies a very large amount of water vapour to the air. When the cooling spoken of above has gone on for some time, and the dew-point has been reached, the transpired moisture, instead of diffusing into the atmosphere in the state of vapour, is condensed at the *stomata*, as the little apertures are called, as soon as it comes into contact with the cooled air. Thus all the dew is not obtained directly from the atmosphere.

Hoar-Frost—or as it is sometimes called *white-rime* or simply *rime*—is deposited instead of dew on those evenings when the radiation cools the overlying air to the temperature of freezing water before any deposition of moisture takes place. Hoar-frost is not frozen dew. It does not first assume the liquid condition, but is precipitated at once in the solid form. Under these circumstances the *dew-point* is at or below the freezing-point.

Rainfall.—Of all the forms of condensed moisture which have now been described the most important, because it is the commonest and most abundant, is rain. We have next to consider how the amount of rain which falls in a place is measured and estimated. This amount is spoken of as the *rainfall* of a place. The student will doubtless have often come across the expression that the annual rainfall of a certain place is so many inches. Thus he may have seen that the mean annual rainfall of Nottingham is twenty-five inches. By such a statement is meant that could we collect all the rain which falls in this town, allowing none to be lost, the amount which would accumulate during an average year would be sufficient to cover a level field in Nottingham to a depth of twenty-five inches.

For measuring the amount of rain which falls in a locality a simple instrument called the *rain-gauge* is used.

There are many patterns of rain-gauges, but the object of them all is the same, viz., to collect all the rain and store it in such a way that there is no loss by evaporation. A very satisfactory form is that designed by Mr. Glaisher, and its construction will be at once understood by reference to Fig. 104. It consists of a metal cylinder, A, in which the rain is stored, and a cover, B, in the form of a funnel. The stem of the funnel is bent back upon itself, as is indicated by the dotted lines in the figure, so that the loss by evaporation may be reduced to a minimum. The graduated cylinder, C, by the side of the gauge is used to measure the amount of rain collected during the previous twenty-four hours from the time of setting the instrument. Of course, the area of the collecting funnel must be known with some degree of accuracy, and also the exact relation between it and that of the graduated vessel in which the water is measured, and when, in addition, the amount of rain has been determined we have all the information necessary for calculating the rainfall of the place.

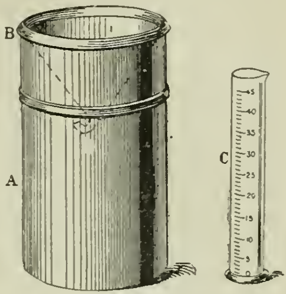

FIG. 104.—Rain-Gauge and Measuring Jar.

In speaking of the manner of recording the amount of rain, the expression *mean annual rainfall* was used, and it will be desirable to make it clear what is thereby meant. One year may be very much wetter than another, *e.g.*, during 1872 a very large amount of rain fell in this country, whereas in the following year the rainfall was unusually small. Thus, by taking any one year we may get an entirely wrong estimate of the amount of rain which generally falls at a place, and to avoid this it is usual to add the amounts of rainfall for several successive years together and divide by the number of years, thus obtaining the average for the years taken, such a result being known as the mean annual rainfall of the place.

Conditions favourable to an abundant Rainfall.—Since rain results from the cooling of air charged with moisture, where the

conditions are conducive to such a lowering of temperature we shall have an abundant rainfall.

(1) This can be brought about by those circumstances which result in *the ascent of a current of damp air which is cooled* (1) *by its passage into colder regions and* (2) *by expansion as it rises.* This is notoriously the case along a belt extending round the globe from about 3° N. to 11° or 12° N. latitude known as the *zone of constant rains.* Here the N.E. trade winds of the northern hemisphere come into contact with the S.E. trades of the southern hemisphere, producing the equatorial belt of calms, above which we have an ascending current of warm moist air which becomes cooled as it rises.

(2) *The contact of warm and damp air with the cold surfaces of the ground.* In those localities where the prevailing winds have this character and come into contact with land in their course, along the coasts marking the collision will be found an abundant rainfall. For this reason the western coasts of many countries are much more watered than the eastern. Great Britain and Ireland afford examples near home where the prevailing south-westerly winds reach us after having travelled across the Atlantic and become thoroughly saturated with moisture as well as warmed by the heat of the Gulf Stream.

The influence of mountains is really felt in both the directions indicated under the above reasons, for there is not only the cooling of contact, but in addition the cooling due to the expansion which results from the air being forced up the side of the mountain range. The greater the altitude of a place on the mountain the greater will the rainfall be there.

Evidently, other circumstances being favourable, proximity to the ocean will be more likely to result in an abundant rainfall than distance from the coast. Decided depressions in the height of the barometer, since they are the result of a diminution in the weight of the atmosphere due to its admixture with water vapour, will generally be accompanied by much rain.

Rainfall of England.—The distribution of the rainfall in this country is at once explained in view of what has been said in the preceding paragraph. Since the mountains of England form three groups arranged down its west coast, viz., those of (1) Westmoreland and Cumberland, (2) Wales, (3) Cornwall and Devon, and since in addition to this the prevailing winds blow from the south-west, the rainfall in these districts will be much higher than elsewhere. The annual rainfall in parts of Cumberland is above 75 inches, while at one place, Seathwaite, it reaches 143 inches, which is the greatest recorded annual rainfall in Europe. In the second of the groups of mountains mentioned the greatest rainfall occurs in the neighbourhood of Blaenau Festiniog where the annual fall reaches upwards of 75 inches. This amount is also recorded in the third mountainous district, in the locality of Dartmoor. Throughout the Lake country the rainfall is over 50 inches in the year, and the same is true of all the mountainous parts of Wales and the higher portions of Devon and Cornwall. If we draw a line from the middle of the Cheviot Hills almost due north and south to Birmingham, and another from this place to Liverpool we shall have

included an area in the north-west where the rainfall varies between 30 and 40 inches per year. The same numbers apply to that part of the southern counties south of the Downs and to the parts of Gloucestershire round the Cotteswold Hills. The central parts of England as far east as Oxford possess a rainfall of from 25 to 30 inches, while that of the eastern counties as far west as this university town is below 25 inches in the year.

Localities of Excessive Rainfall.—The student has learnt the causes which bring about this excessive rainfall; we have now to give some examples which have been recorded. At Cherra Ponge, in the Khasia Hills to the north-east of Calcutta, the mean annual rainfall is 490 inches. At Mahabaleshwar, in the Western Ghauts, the amount is 252 inches; at Vera Cruz, in Mexico, 141 inches have been recorded; at Sierra Leone, 126 inches; and at Pernambuco, in Brazil, 110 inches. These localities of excessive rainfall all fall between the tropics and chiefly near the equator. This would be naturally expected from what has been said concerning the zone of constant rainfall. The student will have no difficulty in understanding why the rainfall at the places given above is so great if he but tries to apply the information given about the causes which tend to such a result, taking into account the situation and environment of each place.

Rainless Districts.—In some localities little or no rain falls throughout the year. This is true of that part of Peru between the Andes and the Pacific Ocean, that is, of course, on the lee side of the Andes; and of that region of California and Utah, protected from the prevailing south-west winds by the Rocky Mountains. The latter region extends down into Mexico and on as far as Guatemala, in Central America. Patagonia, too, lying as it does on the lee of the Andes, is also nearly rainless.

In the western hemisphere a much larger area possesses the same rainless climate. It is divided into two districts by the Hindoo Koosh Mountains to the north-west of Cashmere. On the west of this range the district includes the deserts of Africa, Arabia, and Persia; on the east it is comprised by the desert of Gobi. The absence of rain is accounted for at once when it is remembered that during our summer the whole district is under the influence of the N.E. trade-winds, which, having blown entirely over the land to the north-east of these deserts, have long since deposited their moisture and are known here for their dryness and bleakness. During our winter, in consequence of the apparent motion of the sun, the region becomes more influenced by the south-westerly anti-trades, which have already precipitated their water-vapour on the western coast of Africa, along the Guinea coast especially, before reaching the countries with which we are here concerned.

Geological Action of Rain.—Rain has a twofold action upon the rocks at the surface of the earth. It dissolves some of their constituents (p. 127) and also washes away the lighter insoluble ingredients. This work is often referred to as denudation. An interesting example of the extent of the rain's

activity is seen in the case of *earth-pillars*, like those of Tyrol. The surface rock in the districts where these pillars abound is either a soft clay or shale which is easily worn away. Sprinkled over the surface, however, are lumps of hard rock on which the rain has little or no action. These serve to protect the soft material underneath them, and the result of the continued action of the rain is to produce pillars of the soft clays, each protected by its own covering of hard rock.

Circulation of the Atmosphere.

General Remarks.—That the air is in movement is a fact of common knowledge. We see the results of its motion as we watch the branches of trees swaying to and fro. We feel the impact of the air particles upon our face when we turn towards a strong breeze. We have now to consider several questions having reference to this circulation of the atmosphere. Is there any regularity or order in the way in which winds blow? What causes them? and a host of other questions which will present themselves to the student. Before attempting an answer to such queries as these, it will be convenient to call attention here to the way in which winds are named. In describing the direction of ocean currents, a northerly current is one which flows toward the north, or similarly with any other. But the contrary is true of winds. *The direction of an ocean current is always given as that point of the compass to which it flows, whereas that of a wind is always spoken of as that from whence it blows.*

The Cause of Winds.—In discussing the movements of liquids we found that water always flows from a place of high pressure to one where the pressure is lower. We said it sought its own level. Similar movements take place in all fluids; there is in every case a movement from a point of higher to one of lower pressure until the pressure is equalised. But as has been learnt, the pressure of the atmosphere varies considerably from place to place, and being a fluid there will naturally be a disturbance of the whole, resulting from the endeavour to bring about an equilibrium of pressure. *The air will move from the places where the pressure is high towards those spots where the pressure is low.* These movements constitute *winds*. The winds will be *permanent* if the difference of pressures causing them are

constant throughout the year. They will be *periodic* if the pressure differences only arise at stated intervals. *Variable* winds result from any pressure disturbance which may ensue from local peculiarities of situation or from any other cause. It has been seen that variations in pressure are the result of alterations in temperature and of the increase or decrease of the amount of water vapour held by the air. These causes are, in consequence, to be regarded as the primary factors in bringing about winds.

It has been found that the weight of the atmosphere is least in polar regions and along the equator, while the districts of greatest pressure occur approximately along the Tropic of Cancer and also long the Tropic of Capricorn, in the northern and southern hemispheres respectively. From what has been said above, it is manifest that there will be a movement of air from the Tropics of Cancer and Capricorn towards the poles on the one hand and towards the equator on the other. If the earth were at rest, that is to say, we should have in the northern hemisphere a north wind blowing between the Tropic of Cancer and the equator and a south wind from near the same parallel to the poles ; while in the southern hemisphere there would be a south wind between the equator and the corresponding parallel of latitude and a north wind extending from the same circle to the south pole.

The Trade Winds.—But the earth is not at rest. It is spinning round like a top. The poles are at rest while places on the equator are performing a journey of 25,000 miles in 24 hours, that is, are moving with a velocity of over a thousand miles an hour. Other places on the surface will have a velocity intermediate between these two extremes and dependent upon their latitude. Bearing this in mind, we must refer back to the wind in the northern hemisphere, which would be a north wind were the earth at rest, and would blow between the Tropic of Cancer and the equator. The air moving towards the equator is subjected to two velocities—(1) that which it has in a southerly direction, depending upon the actual pressure difference between the place from which it starts and that towards which it moves ; (2) that which it has in a direction from west to east, due to the earth's rotation. The resultant is obtained in the manner described on p. 29. By applying this method the student will understand that

the direction which the wind will appear to have will be from the *north-east*, and this movement will give rise to the north-east winds which are more or less permanent in the low latitudes we have specified. They are known as the *Trade Winds*, and were so called because of the assistance they rendered to the navigation of trading vessels before the introduction of steamers. They blow with great constancy across the oceans, but are more or less interfered with over the continents, since the local conditions on the land vary very considerably from place to place.

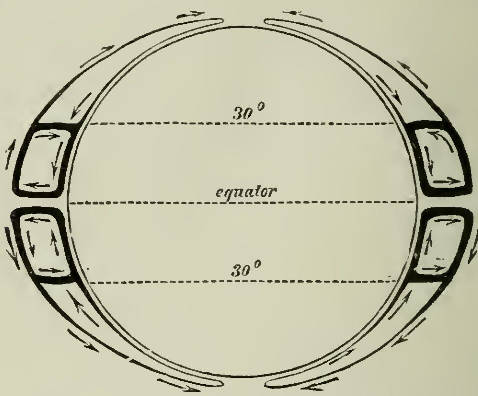

FIG. 105.—Explanation of the Trade Winds and Atmospheric Circulation.

By applying the same reasoning to the southern hemisphere it will be immediately clear that the direction of the trade winds south of the equator will be *south-east.*

The area over which these winds blow is not between the same latitudes either in different oceans of the same hemisphere, or between corresponding latitudes in the two hemispheres. Thus in the Pacific Ocean the N.E. trades extend over the area between 6° N. and 25° N. latitude, while in the Atlantic they are felt between 7° N. and 35° N.

The south-east trade winds of the other hemisphere blow between 2° N. and 21° S. latitude in the Pacific, and between 3° N. and 25° S. latitude in the Atlantic Ocean. These limits are not fixed throughout the year, but vary more or less with the seasons.

Winds of the Temperate Zones.—We have now to see what becomes of the winds which, were the earth at rest, would blow from the tropics in both hemispheres towards the poles as due south and north winds respectively in the northern and southern hemispheres. The air moving north polewards is under the influence of two velocities, one urging it from the south and produced by the pressure difference existing between the two places ; the other tending to make it move from west to east with the earth as it rotates. For similar reasons to those already given, the resultant velocity will be in an intermediate direction, and the wind will appear to come from the *south-west.* It is these winds in the northern hemisphere which constitute the prevailing currents of air in our own country as well as others in the same latitudes.

In the southern hemisphere the winds will manifestly blow from the *north-west*, and are of much greater importance in these latitudes than in those north of the equator. Their course is across oceanic areas which interfere with their permanent character very little. They are spoken of as the *Brave West Winds* and the latitudes in which they blow as the *Roaring Forties.* The direction of these winds is contrary to that of the trade winds themselves, and to mark this fact they are sometimes called the *Anti-trades.* It must be mentioned, however, that this name is often given to those upper currents of air which blow in the atmosphere over the trade winds. These upper winds are the completion of the great convection currents which constitute the winds, for we cannot have a current in one part of a continuous fluid without causing one in other parts.

Belts of Calms.—Zones in which there is very little circulation of the atmosphere occur round the earth in different latitudes. One of the most marked, to which reference has already been made in discussing the causes bringing about excessive rainfall, extends round the globe just north of the equator. It is a line of calm marking the collision of the two sets of trade-winds. These winds, moving in opposite directions with an equal force, more or less exactly neutralise one another, and the resulting belt of calm is marked, amongst other things, by the great rainfall which occurs there. It is often referred to as the *Doldrums.* Other belts of calms occur in the regions of the tropics and are referred to as the *Calms of Cancer* and *Capricorn* respectively. To understand their occurrence it must be borne in mind that it is over the tropics, in the latitudes where the high pressure zone, which we have spoken of in explaining the cause of the winds, exists, that the upper currents corres-

ponding in the northern hemisphere to the north-east trades and to the south-west winds of temperate zones come into collision. That corresponding to the trades is moving from the equator, that brought into existence by the south-west winds from the poles; hence they come into contact moving in opposite directions and produce the calms.

The student should think of the calms rather as places where no permanent winds occur than as districts of absolute rest, for they are subjected to variable winds which are caused by local variations of pressure. The only other similar districts where such calms are prevalent are in the immediate vicinity of the poles where, as the student has learnt, the earth is subjected to very little rotatory velocity.

Land and Sea Breezes.—Near the sea, especially in the tropics, there are well-marked breezes, which result from the different thermal properties of land and water. Water has a higher specific heat, and is also a poorer absorber of heat than land, and consequently during the day the air above the land

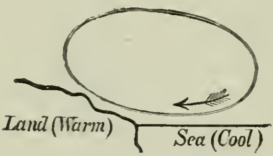

FIG. 106.—Sea-breeze.

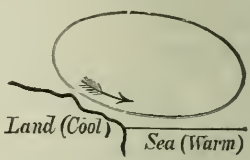

FIG. 107.—Land-breeze.

will get warmer than that above the water, and an upward current of air will be set up over the land. The cooler air from over the sea will flow in to take the place of the air which rises and will constitute a *sea-breeze*. After sunset both the sea and land begin to radiate their heat; the land being a better radiator gets cool quickly, but the sea remains warm. The air over the water consequently gets warmer than that over the land, and the pressure above the sea will be lower than that over the land, causing a current of air from the land out to sea, which is known as a *land-breeze*.

Monsoons.—In describing the trade winds no reference was made to the Indian Ocean, and this was because the conditions here periodically change as a result of the proximity to the great land-masses of Asia as well as of the apparent annual motion of the sun. The name *monsoon* is itself derived from a Malay word meaning a *season*, to mark the fact of the periodical change

in the direction of the winds, that is, the seasonal variation which they undergo. In summer, the Asiatic continent is shone upon nearly vertically by the sun, and therefore it becomes intensely hot compared with the waters of the Indian Ocean to the south. As a natural result the air over the land rises because of the decrease in its density. The air from the relatively cold ocean flows in to take the place of the upward current, and in consequence of the earth's rotation flows from the *south-west* across India, but in directions in other parts depending upon the nearest place of high pressure. This south-west monsoon blows from April to October. In the southern hemisphere, in a manner somewhat similar to that causing an alteration in the direction of the trade winds, the direction of the monsoon blowing in these months is south-east. In winter the conditions have become changed. The sun is now more or less vertical over the latitudes in the vicinity of the Tropic of Capricorn. The air over the Asiatic continent becomes cooled and denser, while that over parts of Africa has become warmed and rarer. There is a wind caused which blows from Asia to Africa in a north-easterly direction, and is felt from October to April.

It must not be supposed that monsoons blow in no places besides the Indian Ocean, for wherever the local conditions interfere with the regular trade winds, these winds will partake of a seasonal character. Monsoons occur for these causes in Madagascar, Guinea, Australia, Brazil.

Hurricanes.—Some writers regard hurricanes as being those storms which occur in the West Indies, but the term is here used in the sense of a storm, which may occur in any part of the world. They generally occur very suddenly, and have most destructive results, but their cause is, as in any other movement of the air, a different barometic pressure of neighbouring localities. If for any reason we have an area developed in which the pressure is small, as we know, the air round this extent of low-pressure will flow in to take its place. The force of the currents inward will, as in previous instances, depend upon the difference of pressure between the air of this area and that outside. The air does not move towards the place of low-pressure in straight lines, but along spiral lines which ascend as the centre of the area is approached. The centre will be a place of calms, where the currents neutralise each other, and as

they move onwards and upwards they travel outwards still along spiral lines.

The incoming spirals are called *Cyclones*, those moving outwards in the higher regions of the atmosphere are called *Anti-Cyclones.* In the northern hemisphere these cyclones move in an "anti-clockwise" manner, while in the southern hemisphere they follow the directions of the hands of a watch. This is a direct result of the earth's rotation.

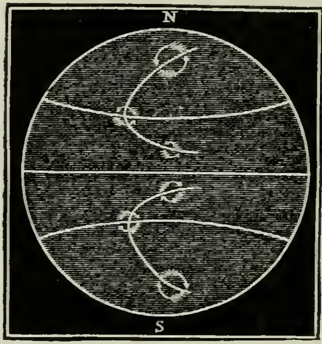

Fig. 108.—Movements of Cyclones in Northern and Southern Hemispheres.

In addition to this rotatory motion the cyclone has a movement of progression, its centre moving onwards at rates depending upon the intensity of the storm. Its direction is usually that of the prevailing wind, and the average rate of movement is from fifteen to thirty miles an hour.

Geological Action of the Wind.—Winds perform two kinds of geological work. They carry materials from one place to another ; and also sometimes cause the disintegration of rocks by driving these transported materials against them with tremendous violence. The work of transportation is not great in our latitudes, but in countries where cyclones occur the amount of materials carried is very considerable. In this way it has often happened that a fertile district has been suddenly converted into a sandy desert ; or, as in other cases, areas marked by a complete absence of vegetation, as a result of the salt with which the soil has been impregnated, have been suddenly covered with a fertile soil. It is a common practice in sandy neighbourhoods, like those of the coast of Lancashire, to grow a species of grass which, by means of its spreading roots, prevents the easy removal of the sand from one place to another.

The disintegrating action of the wind is well seen in parts of California, where certain rocks known as mica-schists, containing hard crystals of garnet, are worn away in a peculiar manner

by the dust-ladened winds which prevail. The mica is very soft, and is consequently easily worn away, while the garnets are scarcely acted upon. The result is that the garnets stand out from the surface of the rock, being connected therewith by thin columns of mica, which are protected by the hard crystals.

The so-called *blood-rain* and *red-snow* are formed by the precipitated moisture collecting the particles of dust which abound in the air as a consequence of the transporting power of the wind.

Chief Points of Chapter XIV.

Fog consists of numerous minute droplets of water, each having a small particle of dust or other matter as a nucleus, and formed near the earth's surface.

Mist is similar to fog, but not so dense, and the particles of water in it are believed to be larger than in fog.

Clouds mostly consist of innumerable particles of water suspended high up in the air; they are elevated mists or fogs. Some clouds, however, are composed of ice particles.

Classification of Clouds.—(1) Cirrus, or curl cloud, consisting of minute particles of ice or snow; (2) Cumulus, or summer cloud; (3) Stratus, or continuous sheets of cloud; (4) Nimbus, or rain-cloud.

Rain consists of drops of water, which are formed by the union of the minute water particles of clouds, and fall towards the earth in consequence of their increased mass.

Snow is the solid form in which the moisture of clouds is precipitated when the temperature is below the freezing-point of water. Snow-flakes always have a regular crystalline form.

The Snow-line is the level, in any latitude, above which snow is always found, on account of the temperature never being above freezing-point.

Hail consists of pellets of ice or snow, frequently made up of concentric layers formed round a nucleus. This stratified structure proves formation in stages and not all at once.

Dew is moisture directly condensed from the atmosphere, and deposited in the form of drops upon objects at the earth's surface. Dew-drops are also formed by the condensation of the transpired moisture of plants.

Hoar-frost is moisture deposited in the solid form upon objects at the earth's surface, when the dew-point is below the freezing-point.

Rainfall is the amount of water that falls as rain; it is measured by the depth of the layer which would cover any given surface if the rain-water had been allowed to accumulate.

Mean Annual Rainfall is the *average* depth in inches of the layer of water which would cover a given surface during a year, if the rain were

allowed to accumulate. It is determined by observing the annual rainfall for a number of years, and finding the mean or average of the values observed.

Causes of Rain, or conditions favourable to abundant rainfall—(1) The ascent of damp air cooled by expansion in rising; (2) the contact of warm damp air with the colder surfaces of the ground; (3) the mixture of masses of hot and cold air.

Wind is air moving from places where the pressure is high towards those spots where the pressure is lower. The differences of pressure are produced by variations in the temperature and moisture of the air.

Permanent Winds.—

lat. 60° N. – lat. 40° N.	South-west Anti-trade winds.
lat. 30° N. – lat. 6° N.	North-east Trade winds.
	The Doldrums—a Belt of Calms.
lat. 2° N. – lat. 25° S.	South-east Trade winds.
lat. 40° S. – lat. 50° S.	North-west Anti-trade winds, or Roaring Forties.

Monsoons are periodical winds strongly felt in and about the Indian Ocean and China Sea.

MONSOONS.	Northern hemisphere	North-east, October to April.
		South-west, April to October.
	Southern hemisphere	South-east, April to October.
		North-west, October to April.

The monsoon that blows from the equator always causes rain.

Hurricanes are extensive whirlwinds, in which the wind blows round a centre and which moves onwards, as a whole at the same time; the direction of which, in the northern hemisphere, is anti-clockwise, and in the southern hemisphere is the same as that of clock-hands.

Land and Sea Breezes.—

Night Breeze
from cooled land to warmer water →

LAND SEA

← Day Breeze
from sea to warmer land

QUESTIONS ON CHAPTER XIV.

(1) (*a*) Draw and describe a rain-gauge.
(*b*) Why is the water of a rain-gauge transferred to another vessel for measuring?
(*c*) What is meant by the statement that "the mean annual rainfall in the Thames Valley is twenty-seven inches"?
(*d*) How has this been determined? (1895.)

(2) Describe—

(*a*) Cloud.

(*b*) Rain.

(*c*) Hail.

(*d*) Snow. (1894.)

and state the mode of formation of each.

(3) State what you know of the nature and direction of—

(*a*) Trade winds.

(*b*) Monsoons.

(*c*) Anti-cyclones.

(*d*) Sea-breezes. (1893.)

(4) What is the source of the water that falls as rain? What becomes of it when it reaches the ground? How do we indicate the quantity of rain which falls upon a given place during a year? (1891.)

(5) (*a*) What becomes of the water of puddles when they "dry up"?

(*b*) What conditions of the air are most favourable to the process?

(*c*) State the reasons why these conditions are favourable. (1890.)

(6) What is meant by the statement that the mean annual rainfall of a place is twenty-seven inches? State what you know concerning the mean annual rainfall of different parts of the British Islands. (1890.)

(7) What are isotherms and isobars?

(8) State what you know of the nature of fog, mist, cloud, rain, snow, hail, dew, and hoar-frost.

(9) Describe land and sea breezes, and state how they are caused.

(10) Name a place in England having a high rainfall. Compare the rainfall on the east and west coasts of our island.

CHAPTER XV

THE OCEANS

Prcportion of Land to Water on the Surface of the Globe.—About three-quarters of the whole surface of the globe is covered with water. The actual extent of this vast expanse is variously estimated by different authorities, but for our purpose it will be sufficient to say that it is about 145 millions

FIG. 109.—The Land Hemisphere.

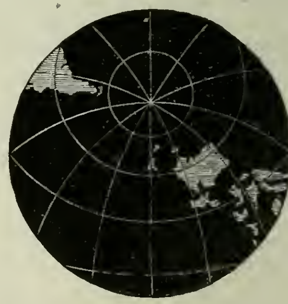

FIG. 110.—The Water Hemisphere.

of square miles out of a total of 197 millions. It is not equally distributed over the whole surface of the planet, as will be evident by an examination of an ordinary school globe, which will reveal the fact that there is far more land in the northern than in the southern hemisphere, or if we take our globe and arrange it so that England is on the top we shall find on looking down upon it that a very large proportion of the hemisphere we can

see is land, but on examining the lower hemisphere that it is almost entirely water. If we examine this extent of land on the top more carefully we shall notice that England is situated at just above its central part.

Division into Oceans and Seas.—For the sake of convenience in locating the position of places on the ocean, geographers have given names to parts of the watery envelope. We need not devote much space to this part of our subject as the student will be already more or less familiar with it.

There are five main divisions to which the term *ocean* is given, they are, in order of their superficial extent, *Pacific*, *Atlantic*, *Indian*, *Antarctic*, and *Arctic* Oceans.

The Pacific Ocean is the portion lying between Asia and Australia on the west and North and South America on the east.

The Atlantic Ocean is bounded on the west by North and South America, and on the east by Europe and Africa.

The Indian Ocean is surrounded by land on the west, north, and east—Africa on the west, Asia on the north, Polynesia and Australia on the east. It extends in a southerly direction as far as the Antarctic Circle.

The Antarctic Ocean is the whole of the extent of water within the Antarctic Circle, the Arctic Ocean that within the Arctic Circle.

Portions of these oceans more or less enclosed by land are referred to as *seas*, such as Baltic Sea, Mediterranean Sea, China Sea, &c.

We must content ourselves with referring the student to an ordinary school book of geography and an atlas for information as to the names of the subdivisions of the five oceans.

Composition of Sea-Water.—The character which is most commonly associated with the water of the ocean is its *saltness*, and, as we have already learnt, this is due to the presence of salts which are dissolved in it. When the great solvent power of water is borne in mind, and we remember that there is a continual addition to the volume of the ocean by the streams and rivers which run into it in all parts of the world, all of them bringing samples of the rocks through which they have percolated, and that from the surface of the ocean there is a continual evaporation going on, removing pure water and leaving the dissolved substances behind, it is not difficult to form some idea of how the saltness of the ocean is brought about. Side by side with this process, which would result in the continual increase in the amount of dissolved material, there is, however, a withdrawal of certain of the soluble ingredients by living organisms, both plant and animal, which extract, some of

them calcium carbonate, others silica, from which to build up their solid parts. There is a greater tendency, therefore, for some of the dissolved compounds to increase than for others. This goes on in the case of the sodium chloride and calcium sulphate until by-and-by the water can hold no more, or it becomes *saturated*, and there is a precipitation of such compounds, forming a deposit.

Moreover, from our knowledge of the nature of the plants and animals which have lived in the ocean in past ages of the world's history,—information obtained, as we shall learn, from the fossil remains of such living things,—there is every reason to believe that the ocean has always been similarly salt.

The composition of the ocean is, on the whole, wonderfully uniform, a result following directly from the incessant movement of its waters, though at the same time there are in places slight variations which are easily explained by the local conditions; for example, where the evaporation is much greater than the average, as in the region of the trade winds (*see* p. 229), the percentage of dissolved material is appreciably higher. Or, again, where there is a continual great addition of fresh-water, as in the vicinity of melting icebergs, the amount in solution is below the average.

§ Expt. 198.—Evaporate a glass or beaker of sea-water and one of ordinary spring-water, and compare the two residues.

A typical specimen of sea-water contains very approximately three and a half per cent. of dissolved salts, that is to say, if we take 100 pounds of sea-water and evaporate it to dryness, we shall have left behind a residue weighing three and a half pounds. This residue is made up of a variety of substances, which are present to the extent shown in the following table, which is due to M. Regnault:—

Sodium Chloride	2·700
Magnesium Chloride	·360
Potassium Chloride	·070
Calcium Sulphate	·140
Magnesium Sulphate	·230
Calcium Carbonate	·003
Magnesium Bromide	·002
	3·505

Much can be learnt from a consideration of such a table as the above. We must first remark what a very large part of the total solids is made up of common salt. If every one hundred pounds of sea-water contains between two and a half and three pounds, the student will have no difficulty in forming some conception of the enormous amount of this compound there is in the whole ocean. Though the amount of calcium carbonate is only three-thousandths of a pound in one hundred pounds of sea-water, or to express it in a different way, only about two and a half grains in 70,000 grains of such water, yet this amount is sufficient to form the shells and other hard portions of the numerous marine animals which possess them.

Gases dissolved in Sea-Water.—Rain, from which the waters of the ocean are of course altogether indirectly derived, dissolves from the air through which it passes samples of the gases contained therein, and the continual contact of water surfaces with the atmosphere, whether those of rivers or of the ocean itself, results in a further solution of different gaseous elements. Finally, there is the carbon dioxide which results from the respiration of the animal life of the ocean continually being added, as well as that given off by submarine volcanoes. The result is that sea-water contains from about two to three per cent. of its volume of dissolved gas. This amount is made almost entirely of oxygen, nitrogen, and carbon dioxide. One-half the amount consists of nitrogen, while the other mostly consists of oxygen and carbon dioxide in equal proportions. It is interesting to note that, while the oxygen occurs in larger proportions near the surface, the carbon dioxide is present to the greatest extent deep down.

Other Properties of Sea-Water.—Density.—As would be expected, since sea-water contains the amount of dissolved material already mentioned, it is found to be heavier, bulk for bulk, than fresh-water. If we take a vessel which at 4° C. exactly holds one pound of pure water and fill it with water from the North Pacific Ocean we shall find that it weighs 1·0254 lb.; if we repeat the experiment with water from the Red Sea the weight is found to be 1·0279 lb.; while with North Atlantic water the number is 1·0266. The numbers, it is seen, are very nearly the same wherever the water is obtained, and since the chemical composition is so nearly constant it is a natural consequence that the density varies little, the one being dependent upon the other. By performing a large number of experiments on precisely this plan and taking the mean of all the results the number 1·0275 has been obtained and is spoken of as the *mean density of sea-water*.

§ Expt. 199.—Show the difference of density of spring-water and sea-water by weighing equal measures on a balance.

Since the deeper we descend into the ocean the greater becomes the height of the water column above us, it is clear that depth and the pressure sustained increase together. Though water is only compressed very slightly by a very great increase of pressure, yet its molecules do become packed a little more closely together as we descend, and the effect is seen by decided increase in the density of the water. At one place where observations were made, the density of the surface-water was found to be 1·0247, while that obtained from a depth of a little more than two miles had a density of 1·0525.

Freezing-Point.—Sea-water freezes at a lower temperature than fresh-water, and the ice which is formed is nearly fresh, for in freezing a large proportion of the salts is left behind. The temperature at which ice begins to form is from 2° C. to 4° C. This varies somewhat with the amount of material dissolved in the water. Experiments show that if a solution of sodium chloride is cooled sufficiently, pure ice separates first at a temperature lower than the freezing point of pure water, and that if the cooling is continued, at 22° C. the whole solution freezes, forming a crystalline substance of definite chemical composition and known as a *cryohydrate*.

Colour.—The colour of the ocean is very variable from place to place, but generally in the open sea where the water is very deep it has a beautiful blue tint. When the water is shallower the colour passes from blue to a bright green. Several suggestions have been made to explain these colours, but it is quite satisfactory to regard the hue as belonging to the water itself. Pure water if seen through a great depth is quite blue in appearance. Should impurities which are not dissolved be present, that is, substances simply held in the water in *suspension*, as it is called, the water may assume other tints, *e.g.*, parts of the Pacific Ocean are of a red colour due to the presence of minute animals; the Yellow Sea gets its name from the fact that it has been so coloured by sediment brought down by rivers; the Red Sea is said to get its name from a microscopic plant of that colour which is present in large numbers.

Temperature.—The temperature of the ocean water at various depths is determined by using a self-registering thermometer specially designed for the purpose, and constructed to bear the immense pressure it will be subjected to when sunk to any considerable extent. It is beyond the scope of this little book to give a full description of it, and of the manner in which

it is used. It will be sufficient here to simply enumerate the chief results of the work of various expeditions, such, for example, as that of the *Challenger*. The temperature of the surface waters of the ocean varies fairly regularly with the latitude. It

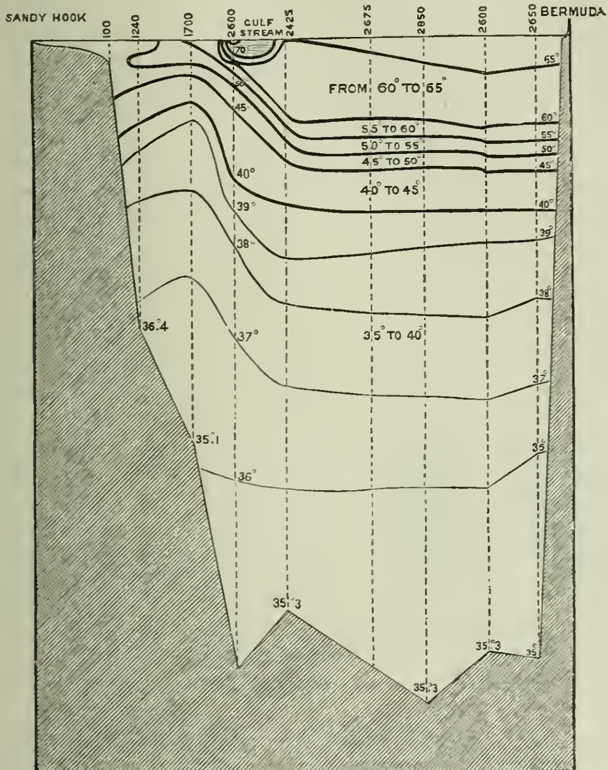

Fig. 111.—Section of the Atlantic Ocean between Sandy Hook (New York) and Bermuda. Dotted lines show depths, the others are lines of equal temperature.

is greatest in the tropics, where it sometimes reaches a temperature of 86° F. (30° C.), as at places near the equator ; but, speaking generally, it can be said to vary from 60°–80° F. (15°–25° C.). The temperature falls as the poles are approached until a tem-

perature slightly below the freezing-point of pure water has been reached well within the Arctic Circle.

This variation with latitude is a natural consequence of the obliquity of the earth's axis. The rays of the sun fall upon the surface in polar regions at a much greater angle than in tropical districts, and as a consequence there is a far greater absorption of heat by the atmosphere in the former than in the latter case, or more heat reaches the water in the torrid zone than elsewhere. The difference between the highest summer temperature of the surface water and the lowest winter temperature is greatest in the temperate zones, where it is as much as ten degrees Fahrenheit, while this difference is least near the equator and poles. The daily variation of temperature is quite insignificant, rarely being more than a single degree on the Fahrenheit scale. This constancy in the temperature results from two of the properties of water with which the student has already become familiar, viz., its high specific heat and its bad conducting power. As a consequence of the first named, water requires a large amount of heat in order to warm it, but once having its temperature raised, it loses heat again with a corresponding difficulty. The second characteristic explains what has been noticed everywhere throughout the oceans, viz., that the heat from the surface water does not spread throughout its mass. A glance at Fig. 111 will show that the temperature of the water at a comparatively small depth is very much lower than at the surface. At a depth of five hundred fathoms, or a little over half a mile, a temperature of 40° F. (5° C.) is reached, and it gets very little lower from this depth to the bottom, for the lowest reading of the thermometer in the figure at a depth of 2,650 fathoms is 35° F. (2° C.). The same fact is clearly brought out in the following table:—

THE MEAN TEMPERATURES FOR ALL THE OCEANS AT DIFFERENT LEVELS.[1]

Depth in fathoms.	Temperature in degrees Fahrenheit.	Depth in fathoms.	Temperature in degrees Fahrenheit.
100	60·7	900	36·8
200	50·1	1000	36·5
300	44·7	1100	36·1
400	41·8	1200	35·8
500	40·1	1300	35·6
600	39·0	1400	35·4
700	38·1	1500	35·3
800	37·3	2200	35·2

[1] From *Natural Science*.

Determination of Depth of the Ocean.—A careful survey of part of the ocean was first made before the laying of the telegraph cable between Ireland and Newfoundland. In 1853 the U.S. brig *Dolphin*, with Lieutenant Berryman in command, surveyed the North Atlantic, while in 1857 Captain Dayman, in H.M.S. *Cyclops* thoroughly surveyed the same ocean between Newfoundland and Ireland. This was done by means of a long series of soundings. In order to prevent the drifting of the line, a difficulty which vitiated some of the early observations, the following apparatus was adopted by the observers on board the *Challenger*, and is known as the "Hydra Machine," since it is a modification of the apparatus used on H.M.S. *Hydra*. In Fig. 112. *a* is an iron tube about five and a half feet in length and two and a half inches in diameter. It is provided at its lower end, *e*, with a pair of valves which open inwards. Supported by a sling at *c* are several perforated heavy iron weights which are threaded on to the tube. The apparatus is so designed that when it comes in contact with the bottom, the sling is detached, after the tube has penetrated into the material on the floor and filled the lower end of the tube with a specimen, which the valves prevent from escaping. The weights themselves are left behind.

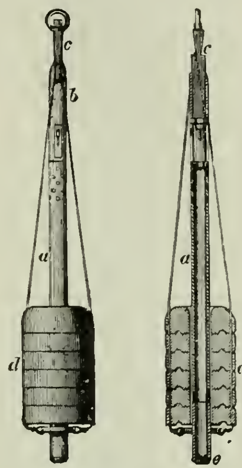

Fig. 112.—The Hyra Sounding Machine.

Results of Soundings.—Atlantic Ocean.—The soundings which have been made provide data for the construction of sections across the ocean, showing the shape of the basin in which the waters are contained, enabling us to obtain almost as good an idea of its form as if we could drain off all the water and walk over the sea-floor. In the case of the North Atlantic, from Valentia, on the West of Ireland, to Trinity Bay, Newfoundland, there is a gradual slope from the land down into the sea ;

the inclination is nowhere "more than one in twenty-five, or that of a hill of moderate steepness." The depth increases after we get two hundred miles from the Irish coast to about two thousand fathoms, and remains between two and two and a half thousand fathoms for some distance, until the floor begins to rise again into a kind of submarine table-land or plateau of a thousand miles in width, over which the water is rarely more than fifteen hundred fathoms, and generally nearer one thousand fathoms. When the "telegraph plateau," as it has been called, has been passed, the same differences in depth are experienced, though in the reverse order, the water first gets deeper again down the western edge of the submarine table-land and in due course the floor rises by easy gradations into the Newfoundland bank.

The telegraph plateau extends in a northerly and southerly direction throughout the whole extent of the Atlantic Ocean, and names have been given to it in different latitudes. Thus, north of the equator it is called the "Dolphin Rise," after the ship of that name, to which reference has been made; while south of the equator it is spoken of as the "Challenger" ridge, the intermediate portion going under the name of the "connecting ridge." The student is recommended to carefully examine the sections of the oceans which are given in Fig. 113, and to form a mental picture of what their appearance would be if the water could be removed and a bird's-eye view of the floor obtained. If such steps are taken he will be struck with the absence of those irregularities which mark the superficial aspect of the land. The superincumbent waters effectually prevent the atmospheric agencies, which are so active in sculpturing the land into its endless variety of hill and dale, from causing any similar wasting away of the sea-floor. The sea-floor is monotonously level. The only abrupt elevations from its even surface occur in the case of the oceanic islands which rise precipitously, and which, in the absence of the waters above, would constitute mountains. This is clearly brought out in Fig. 113, where the submarine mountain, the uncovered peak of which forms the island of Galapagos is seen towering up through 3,000 fathoms of water and attaining a total height of 20,000 feet, rivalling Mount Chimborazo.

We may summarise what has been said by stating that,

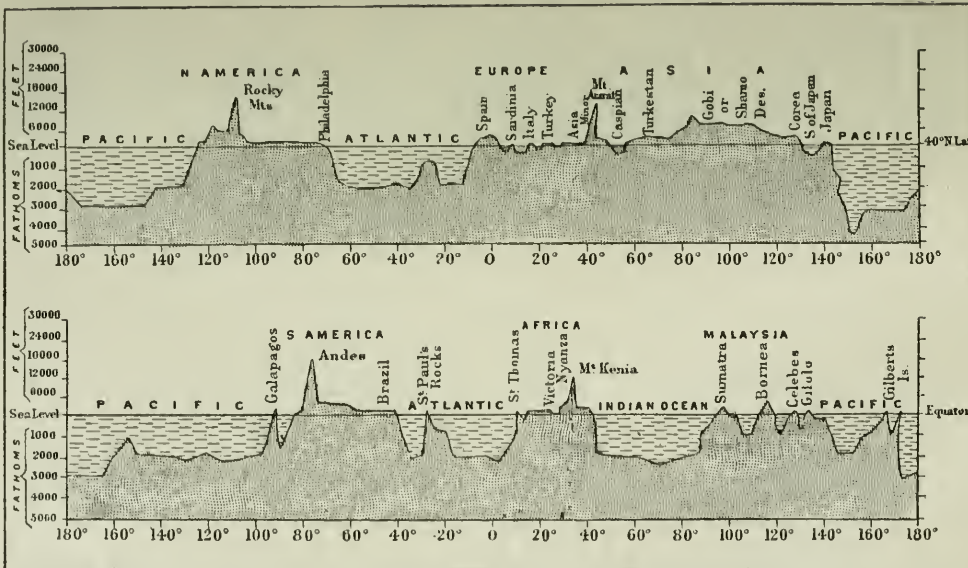

FIG. 113.—Approximate Section of the World, showing elevation of the land and depth of the Sea along the parallel of 40° N. Lat. and the Equator. From the Graphic School Atlas (George Philip and Son).

speaking roughly, we have a more or less median table-land with a deep valley on either side. In some one or two parts of these valleys very decided hollows occur. The first of these "abysses," lying near the Virgin Islands, has a depth of 4,560 fathoms. Another lies to the south-east of North America, between the West Indian Islands on the south and the Bermudas on the north. The soundings here reveal a depth of 3,875 fathoms or upwards of four miles. The third occurs in about the same latitude on the other side of the ocean, to the west of the Canary Islands, and its depth is about 3,150 fathoms. A fourth depression has been found in the South Atlantic, roughly near the middle of the ocean between the east coast of Brazil and the island of St. Helena. If we take the average of all the soundings which have been made in the Atlantic we should find it would work out to about 2,000 fathoms, which we can speak of as the average depth of this ocean.

Pacific Ocean.—On the whole, the Pacific is a deeper ocean than the Atlantic, its average depth being about 3,500 fathoms, though in some places very much greater depths have been reached; thus off the Ladrone Isles (latitude about 15° N., longitude about 152° E.) a measured depth of 4,575 fathoms, or about five miles, was recorded; off the Kurile Islands, between Japan and Kamtchatka the depth was found to be 4,655 fathoms. The deepest sounding yet known was obtained by H.M.S. *Penguin* in 1895 near the Kermadec Islands, where a depth of 5,155 fathoms was found.

There are several submarine table-lands over which the water does not exceed a depth of 2,000 fathoms. One of these stretches in a north-westerly direction from the coast of Chili towards the depression near the Ladrone Islands which has just been referred to; another of lesser extent occurs to the south-east of the Australian continent, and it is upon it that New Zealand is situated. The islands of the Malay Archipelago rise from a third, which occupies the area between the south-eastern portion of Asia and Australia. Speaking generally, we may say that the Pacific Ocean presents many remarkable irregularities, a good idea of which will be obtained by looking at an ordinary map of this ocean and bearing in mind what has been said about islands which occur dotted over the great expanse of water which constitutes the ocean. There is

no feature of exceptional interest about the Indian Ocean. Its average depth can be taken as about 2,600 fathoms. So little precise knowledge of the other oceans is even yet to hand that we shall make no special reference to them.

Comparison of the Height of Continents with Depth of Oceans.—In measuring the height of any place it is customary to speak of its height above the *sea-level*, using the level of the ocean as a datum line. It is desirable that the student should understand the significance of the expression, for every one knows that the rise and fall of the tides causes an alteration of its level twice each day, at all events near the land. The Ordnance Survey authorities have arranged that, so far as their maps are concerned, *sea-level shall mean the mean height of the sea between high- and low-water mark at Liverpool.* But this is not the only starting-point which is used, the Trinity House authorities measure heights from the high-water mark at London Bridge.

The mean average height of the continents has been estimated at 1,440 feet above the sea-level, by which we mean that if

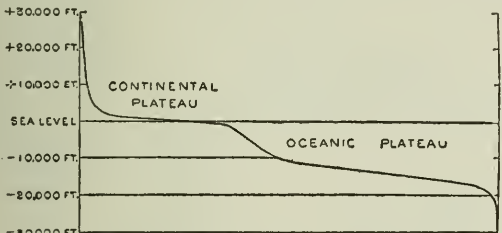

FIG. 114.—Generalised Profile, showing relative Areas of the Earth's Surface at different Heights and Depths. (Gilbert.)

the mountains were all levelled and the valleys filled up, the height of the land thus formed would be what we have stated. The mean average depth of the oceans can be put at about 11,300 feet below the sea-level. The height of the highest mountain, Mount Everest in the Himalayas, is about five miles, and as has been seen the greatest depth of the ocean is also about five miles. This will at first appear to the student to be a very great height and depth respectively. But if he will

consider that the radius of the earth is 4,000 miles he will see that even if he take the distance from the top of the highest mountain to the bottom of the deepest abyss in the ocean, he will only obtain a length of ten miles, or the one four-hundredth of the total radius. By instituting a comparison between the average height of the continents with their total area, which can be taken as roughly 51,886,000 square miles, or the average depth with the total area of the oceans, which we have stated approximately as 145 millions of square miles, the student will be properly impressed with the insignificance of the land elevation and with the comparative shallowness of the oceans.

Chief Points of Chapter XV.

The Proportion of Land to Water on the earth's surface is, roughly, as one is to three. This will be seen from the following table:—

	Square miles.
Total area of Continents	52,000,000
,, ,, ,, Oceans	145,000,000
,, ,, ,, Earth's surface	197,000,000

	Feet.
Average height of Continent	1,440
,, depth of Oceans	11,300

Mean Areas and Depths of Oceans.—

	Area in square miles.	Mean depth in fathoms.
Pacific Ocean	71,000,000	3500
Atlantic ,,	34,000,000	2000
Indian ,,	28,000,000	2600
Antarctic Region	7,000,000	—
Arctic Region	5,000,000	—

Composition of Sea-water.—Proportion of dissolved solids, about three and a half per cent. by weight. About three-quarters of this consists of common salt, and the remaining quarter is made up of chlorides of magnesium and potassium, sulphates of calcium and magnesium, calcium carbonate and magnesium bromide. Dissolved gases: oxygen, nitrogen, and carbon dioxide.

The Specific Gravity of Sea-water is, on the average, 1·027. but it differs slightly according to (1) depth; (2) temperature; (3) degree of salinity of the water from which samples are taken.

The Freezing-point of Sea-water is about 28° F., that is 4° F. lower than that of ordinary water.

The Temperature of the Oceans vary (1) according to latitude (from about 80° F. at equator to about 28° F. in polar regions, in the case of surface water); (2) according to depth (from about 61° F. at 100 fathoms to 35° F. at 2,200 fathoms). The following table shows roughly the temperatures in five latitudes at different depths.

	Latitudes.					
Depths in Fathoms.	3° S.	5° N.	23° N.	55° N.	78° N.	
0	78°	78°	73°	57°	32°	Temperatures
250	48	48	48	46	33	
500	47	47	45	42	33	
1000	38	38	36	35	33	

All water below about 700 fathoms has a temperature less than 40° F.

Questions on Chapter XV.

(1) State what you know concerning the composition and specific gravity of sea-water.

(2) How does the density of sea-water differ from that of spring-water, and why?

(3) Write a general description of the differences of temperature of the sea—

(*a*) At the surface in different latitudes.

(*b*) At different depths in the same latitude.

(4) What is the average depth of the Atlantic Ocean? What is the greatest trustworthy depth yet measured in the oceans?

(5) Name as many of the constituents of sea-water as you can remember.

(6) How would you prove experimentally that sea-water contains substances dissolved in it?

CHAPTER XVI

CURRENTS IN THE OCEANS

Ocean Currents.—Causes.—There are several causes at work tending to produce movements in the waters of the oceans. They have already been incidentally referred to, and can be very satisfactorily enumerated at once.

(1) *Action of the prevailing winds.*

§ EXPT. 200.—The production of surface currents by wind may be illustrated by the aid of a pair of bellows and a basin of water, with sawdust or other floating particles.

In this connection the comparative shallowness of the ocean must be again insisted upon, for it is only by bearing this in mind that any conception of the power of the wind can be attained.

(2) *The heating effect of the sun in tropical regions.* It has already been sufficiently brought before the student's attention that the effect of heat upon liquids is to make them expand, causing a given mass to occupy a larger volume, and so become lighter bulk for bulk. The result will be a rising of the lighter waters and a sinking of the heavier colder waters to take their place, precisely as has been described under convection currents.

(3) *The increase in saltness and consequently of density of the water as a result of evaporation.* The waters of the ocean contain solid substances in solution. When heated they give off pure water in the form of vapour, the saltness consequently increases and with this the waters become heavier bulk for bulk thereby disturbing the equilibrium.

It is evident that the second and third of these causes produce contrary effects and tend to neutralise one another. It is most probable that the winds constitute the motive force which results in the production of the great regular movements of the water which are referred to under this heading. The winds are set up by the sun and the amount of evaporation depends upon temperature, so that really the prime cause of oceanic circulation is solar energy.

The general result of the difference of temperature in equatorial and polar regions is that there is a tendency for warm

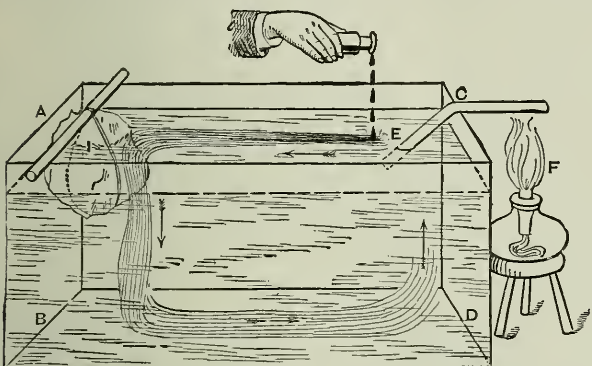

FIG. 115.—Circulation of Water.

surface currents to flow into higher latitudes, while a cold undercurrent creeps along the ocean bottom from the poles towards the equator. This action can be illustrated experimentally.

EXPT. 201.—Place a piece of ice in a trough of water, A B C D, and at the other end of the trough arrange a metal rod E, kept hot by a flame F. Pour a little coloured liquid into the trough, and notice the general movement of the water as shown in Fig. 115.

The Great Equatorial Current.—North and south of the equator we have, as the student has learnt, blowing with unceasing regularity, the system of air currents known as the trade winds. In the northern hemisphere these blow between latitudes 6° N. and 35° N. from the north-east to the south-

west; while in the southern hemisphere they blow throughout corresponding latitudes from the south-east towards the north-west. The consequence is that they meet in the neighbourhood of the equator and their resultant acting upon the waters causes them to move towards the west. Were there no land-masses to interfere with its course, this would produce a great equatorial current round the earth. But as the student has seen, the continents of South America and Africa extend in a northerly and southerly direction, that is, at right angles to the path of the current, and prevent its continuous course round the globe, causing it by coming into contact with the land to divide into the various currents which will be immediately described.

Currents of the Atlantic Ocean.—It will be most convenient to describe the currents of the different oceans in order, beginning with the Atlantic, and we cannot do better than start with the Equatorial Current which, resulting as we have described, begins its westward journey from the West African coast in the neighbourhood of the Gulf of Guinea, not far from the Congo River. It continues its occidental course until it reaches the middle of the ocean, when it begins to divide into two branches, and when it arrives within a distance of about 300 miles of Cape St. Roque, the extreme easterly point of Brazil, the division is completed, one part of the current moving in a north-westerly direction along the northern coast of South America, as the Guiana Current, passes through the Caribbean Sea into the Gulf of Mexico; while the other part, which constitutes a less pronounced current, travels along a south-westerly path down the eastern coast of South America under the name of the *Brazil Current*.

We must follow the course of these branches separately. The northern current, which we traced to the Gulf of Mexico, passes round the Gulf and emerges through the Florida Straits between the State of Florida and the island of Cuba as the *Gulf Stream*, which travels in a north-easterly direction along the line of the United States coast until it arrives at the island of Newfoundland. Its impact therewith causes some amount of deflection, and with a much more decidedly eastern direction it starts its course towards Europe, and its journey as far as the Azores being completed, it divides; one branch takes a southerly sweep towards the tropics, the other travels northward, finally

FIG. 116.—Ocean Currents. From the Graphic School Atlas (George Philip and Son).

coming into contact with the British Isles and the western coast of Norway, and eventually merges into the north-polar waters.

The Brazil Current flows at some distance from the South American coast, at least 200 miles away ; its rate of travel is considerably lessened after passing Buenos Ayres by the current produced by the inflowing La Plata River, and, gradually declining, it is lost by the time Tierra del Fuego is reached.

An account of the currents of the Atlantic would be incomplete without a mention of the cold current from the Arctic regions, which, since it flows down from the coast of Greenland past Labrador, is spoken of as the *Labrador Current*. Part of the waters constituting this current remains at the surface, flowing in a south-westerly direction down the North American coast, between it and the Gulf Stream, the other greater part sinks and travels south under the warmer waters of the Gulf Stream.

Characters of the Gulf Stream.—The student should think of this current as a river of warm and light water flowing over the colder heavier waters which make up the bulk of the ocean. It is not large, being only about 100 fathoms deep, as Fig. 111 plainly shows, and something like 120 miles broad at its widest parts, which is not very much for a river of between three and four thousand miles long. It gets cooler and cooler after leaving Florida, where it has a temperature of 86° F. But at the same time, since the average temperature of the ocean gets less as we get into higher and higher latitudes, it still remains very much warmer than the waters which surround it. Thus off Florida it is 9° F. above the temperature of the open ocean, while off Newfoundland in winter its temperature is more than 25° F. above that of the water through which it flows. When mid-ocean is reached it is still 10° F. above the temperature of the surrounding sea.

The amount of heat which it carries with it to our islands and to other countries in the west of Europe is very considerable. Judging from its latitude, London would be expected to have a winter temperature of 17°, but, thanks chiefly to the influence of the Gulf Stream, its mean winter temperature is something like 38°.

As regards the velocity of this stream of warm water,—which it may be said in passing sets a southern limit to the existence of icebergs from North Polar regions,—it diminishes fairly rapidly from Florida, where it travels at upwards of four miles an hour,

before reaching Philadelphia it has slowed down to less than three miles, while off Newfoundland it covers no more than one and a half miles in this time, and onwards throughout its remaining course the speed similarly diminishes, the whole journey taking something like eighty days for its completion.

Currents of the Pacific.—These are neither so pronounced nor so well known as those of the Atlantic. Their course is impeded very considerably by the prevalence of oceanic islands and reefs and by a variety of local conditions which will become more evident as we proceed. Following the same plan as in the case of the Atlantic Ocean we shall begin with the equatorial current, which starts travelling westward from the west coast of Central America, whence it has a clear course across the Pacific to the islands of the Malay Archipelago. Even before arriving at its destination it splits up giving rise to a south-westerly branch which passes along the eastern coast of Australia, between it and New Zealand under the name of the *New South Wales Current*. A large part of the Equatorial Current travels in among the islands of the Archipelago, becoming subdivided into a variety of branches, and becomes further complicated by the *monsoon drifts* with which the student has already become familiar. The remaining part of the Equatorial Current moves in a north-easterly direction along the east coast of Asia past Japan, from which country it takes its name the *Japan Current*, on past Kamtchatka until it comes to the Behring Strait, which is, however, too narrow to allow it an exit and the current flows along the shores of Alaska and British Columbia past California to become again, off Central America, merged in the westward-flowing Equatorial Current.

The New South Wales Current moves southward until it becomes lost in the western portions of the cold waters of the Antarctic Ocean. But the westward movement of the waters constituting the Equatorial Current necessitates a movement of cold water from somewhere to take their place ; this tendency gives rise to the *Antarctic Drift Current*, which moving in a north-easterly direction comes into contact with the southern branch of the American continent where it is caused to divide, one portion moves up along the west coast of South America as *Humboldt's Current*, sometimes called the *Peruvian Current*, and eventually flows into the Equatorial Current. This current,

which moves along the coasts of Chili and Peru, is one of cold water, its temperature being nearly 10° lower than that of the surrounding ocean. The other branch of the Drift Current flows round Cape Horn and eventually joins the Brazilian Current of the Atlantic Ocean.

Currents of the Indian Ocean.—Though there is an Equatorial Current in the Indian Ocean, yet since it is of so much smaller extent and subject to such ever-changing influences from the variable winds of the district, it is not nearly as decided as in the wider expanses of the two oceans which have been dealt with already. The westward movement of the waters which is referred to as the Equatorial Current, divides to the north of the island of Madagascar, the larger portion which travels between the mainland and this island is called after the channel through which it passes the *Mozambique Current*, the other portion moves round the eastern side of Madagascar and well to the south of the island re-combines with the former portion to constitute the *Cape Current* which mainly doubles the Cape of Good Hope, though a smaller part is turned back to form the *Counter Current* of the Indian Ocean.

The Ocean Currents can be arranged in Systems of Vortices.—The examination of the map showing the ocean currents and their directions reveals the fact that the various currents which have been enumerated and described can be arranged into groups, each forming a huge vortex with comparatively still water in its centre. Thus if we trace out the course of the following currents in the North Atlantic, viz., the Equatorial, Guiana, Gulf Stream, and Guinea, it will be seen that they form a complete cycle, the currents constituting the circle all moving in the direction of the hands of a watch or "clockwise," and forming a right-handed vortex. Similarly the Equatorial and the Brazil currents with the northward-moving cold water from the Antarctic which passes up past Cape Colony along the west coast of Africa, together make up a left-handed vortex, or one moving in the opposite direction to the hands of a watch, *i.e.*, "anti-clockwise."

In the Pacific Ocean, too, the Equatorial and the Japan currents, with the continuation of the latter down the west coast of North America, can all be considered as making up a right-handed vortex or a system of currents moving in a clock-

wise manner in the North Pacific ; whereas the Equatorial and New South Wales Currents with the colder Humboldt's Current all move in an anti-clockwise manner, forming a left-handed vortex in the South Pacific.

The Equatorial Current and the Mozambique Current in the Indian Ocean similarly help towards a left-handed vortex in this ocean.

As we might suppose, the central part of each of these vortices is comparatively still water and its existence is marked in all cases by a luxuriant growth of seaweeds of different species, including one, the *Sargassum bacciferum*, from the presence of which the still area is called a Sargasso Sea. Within this region there is also an abundant animal life, which includes many varieties of Crustacea and Mollusca. It is probable that these seaweed-covered districts have supplied many of the oft-reported sea-serpents, for to an imaginative mariner at a distance the gentle up and down movements of water thus covered could easily be construed into the serpentine movement of some huge sea-monster.

Wasting Action of the Ocean upon the Land.—It is clear that this occurs almost entirely along the coast line of the continents. The ocean currents and movements of the sea other than those on the beach have little if any effect in wearing away the land. The work of the *Challenger* Expedition has shown that the floor of the deep parts of the ocean is covered with a fine muddy deposit, which it is quite evident would not remain undisturbed were there any very perceptible movements of the oceanic waters. In those parts of the ocean sufficiently near to the land for their waters to hold sand or other material in suspension, any movement on their part will bring about a certain amount of wearing away of the sea-floor, but nothing of any great importance. The bulk of the destructive work accomplished by the sea is above low-water mark. Its extent is generally greatly magnified, the estimates which have been formed of its amount have been exaggerated as a result of dwelling too much upon the activity of the ocean during storms. The work which is accomplished by the sea is of several kinds. First and foremost is the work of erosion effected by the waves, which, dashing against the cliffs, hurl any loose material within their reach with a violence which is ordinarily very great, and

during storms simply stupendous. The noise of shingle being moved in this manner can be heard at a distance of several miles. Not only are the cliffs broken and worn into stacks, buttresses, and needles (Fig. 117), but the stones themselves are ground and worn until they assume the size and smoothness with which all visitors to the western watering-places of these islands are quite familiar.

FIG. 117.—The Wasting Action of the Ocean upon the Land.

Naturally, the extent of this erosion will depend as well on the softness of the rocks constituting the cliffs as on the violence of the seas. It would be to the western coasts of Ireland, Scotland, and some parts of England that one would naturally go for the best examples of the kind of work we are considering, for it is there that the rocks are exposed to the full fury of the

Atlantic waves. At the same time, since, generally speaking, the rocks on the east coast are so much softer than those of the western shore-line, the *rate* of erosion is there much greater than in the west counties. Some parts of the coast of Yorkshire and Lincolnshire are said to be worn away at the rate of three feet per year, while on the western coast there would not be this amount of erosion in a century. But the breakers themselves are often of sufficient force to wrench off huge masses without any aid from loose detritus. Many examples are on record, but it will be sufficient for our purpose to instance the case cited by Mr. Stevenson of the moving of a block weighing 50 tons by the waves at Barrahead in the Hebrides. The alternate compression and expansion of air in the crevices of rocks exposed to heavy breakers often dislocates heavy masses of stone far removed above the direct reach of the waves. The hydrostatic pressure (p. 265) of those portions of large waves which enter passages in the cliffs also acts in forcing off huge masses from the rocks.

Chief Points of Chapter XVI.

Causes of Oceanic Circulation.—(1) Action of prevailing winds; (2) heating effect of sun upon water in different latitudes; (3) increase of salinity, and consequently of the density of sea-water, as a result of evaporation.

Currents in the Ocean—see Table on p. 262.

Wearing away of Coast Lines.—The means by which the sea wears away the coast are—(1) the direct impact of waves against the land, hydrostatic pressure being called into play; (2) masses of rock and shingle are lifted by the waves and hurled against cliffs; (3) pebbles are dragged backwards and forwards over one another and eventually ground into fine sand.

Questions on Chapter XVI.

(1) State the reasons of the following:—
  (*a*) The warmth of the sea at its surface compared with its coldness in its deeper parts.
  (*b*) The warmth of the atmosphere near the earth compared with its coldness at great elevations. (1896.)

(2) How would you demonstrate to a class the effects of wind and convection in causing circulation of water?

(3) Describe the chief currents in the Atlantic Ocean.

(4) What are the chief causes which produce ocean currents?

(5) Write a short account of the action of the oceans upon the land.

(6) Trace the course and direction of the ocean vortices, of which the Great Equatorial Current forms a part.

CURRENTS IN THE OCEAN.

ATLANTIC OCEAN.	PACIFIC OCEAN.	INDIAN OCEAN.
EQUATORIAL CURRENT divides into GUIANA C. passes through Caribbean Sea into G. of Mexico, emerges near Florida as the GULF STREAM which near Azores divides into NORTH BRANCH to W. Europe SOUTH BRANCH becomes GUINEA C. which rejoins Equatorial C. BRAZIL C. flows South and dies away near Magellan Strait.	EQUATORIAL CURRENT divides into 1. South-westerly branch the NEW SOUTH WALES Current becomes lost in cold waters of the Antarctic Ocean. 2. Part which subdivides into various currents among islands of Malay Archipelago. 3. North-easterly branch the JAPAN CURRENT passes round east coast of Asia and west coast of N. America and rejoins Equatorial Current.	EQUATORIAL CURRENT gives rise to MOZAMBIQUE CURRENT which becomes the CAPE CURRENT and turns eastward causing COUNTER CURRENT.
COLD CURRENT: LABRADOR CURRENT part of which flows from coast of Greenland past Labrador down east coast of N. America—other part sinks and flows *beneath* Gulf Stream.	COLD CURRENT: HUMBOLDT'S CURRENT from the Antarctic Ocean passes up west coast of S. America and joins the Equatorial.	

CHAPTER XVII

RIVERS AND GLACIERS

Circulation of Water.—The student has probably been struck with the intimate relation which exists between many of the processes which we have now considered. He has had his attention called to the ceaseless evaporation which goes on from every surface of water. The heat of the sun being most intense in tropical regions, we have seen, causes the greatest quantity

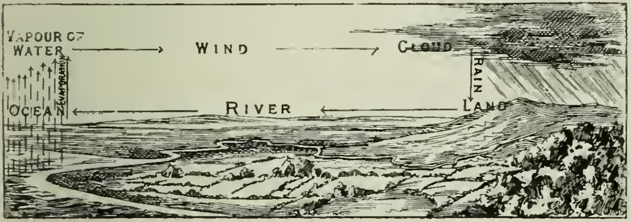

FIG. 118.—Circulation of Water in the Air and upon the Land. From Gregory's Physiography Diagrams (Chapman and Hall).

of water to be converted into vapour there; but though the amount diminishes as the temperature falls there is still some evaporation going on even from the surface of ice. This water vapour, existing in an invisible condition as long as the temperature is high enough, becomes condensed as soon as the air is cooled below the dew point, and falls to the surface of the earth, either as rain or one of the other forms of condensed

moisture with which we have become acquainted. This rain, &c., may fall directly into the sea or upon the land. If the latter is its fate it partly flows off into streams or rivers, or, percolating through the soil and underlying rocks, reaches the surface again later as a spring to feed some river. In every case either directly or indirectly it eventually reaches the sea and so supplies the incessant loss there caused by evaporation. Fig. 118.

Springs.—To properly understand the formation of springs reference must first be made to the varying power possessed by rocks of allowing water to percolate through them. Some rocks constituting the parts of the earth near the surface allow water to pass with ease. They are very *porous*. Others scarcely allow any water to find its way through them and are spoken of as *impervious*. Rocks of a coarse or loose texture will be of the first kind, such, for example, as beds of sand or gravel. Those where the particles are more closely packed will offer much greater resistance to the passage of water, and clay can be cited as a good example of an impervious rock.

Surface Springs.—The formation of simple springs of this kind will be readily understood by reference to Fig. 119. This shows a section across a valley, by which we mean a drawing showing how the beds making up that part of the earth are arranged, and which we should see if we could cut across the valley and remove the rocks on one side of the incision.

FIG. 119.—Surface Springs. *b* are porous, *a* impervious beds.

The beds (*b*) are made up of sand and gravel, those marked (*a*) are of clay. The rain which falls in this neighbourhood will partly flow over the surface, but the greater part will sink into the ground and will meet with little obstruction to its free course until the bed of clay is reached, since, as we have seen, sand and gravel are very porous. Reaching the bed of clay it will be unable to sink further and will consequently collect at the line of junction. The result will be that where the sand has been worn

through exposing the clay, as shown in the figure between *ss*, we shall have the water, which has collected in the manner described, issuing in the form of a spring. It is at once evident, in view of the nearness of the underground water to the surface, that springs of this kind will be immediately dependent upon the rainfall. In seasons of drought the spring will cease, while in rainy years there will be an abundant supply of water. The water which issues from surface springs is, as the student will perceive, very liable to be contaminated with drainage and other impurities taken up from the surface.

Springs caused by Hydrostatic Pressure.—It is comparatively rarely that rocks are as simply arranged as is shown in Fig. 119. As the student will learn, the solid exterior of the earth has undergone all sorts of movements, having been twisted, contorted, and broken by the pressure of underground

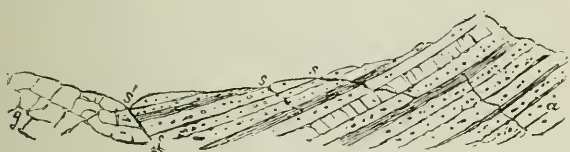

FIG. 120.—Deep-seated Springs rising from a fault at *f* and from joints at *ss*.

steam and by the force of contraction as the earth has cooled. In this way *faults* are formed, and the rocks are caused to break up in a manner called *jointed.* In Fig. 120 we have a section showing both these phenomena. At *f* a fault occurs bringing rocks of a different kind into juxtaposition at the place where the "break" or fault has taken place. At *s* joints occur; these are dividing planes in masses of rock, such as sandstone, brought about by pressure. The darkly shaded beds are rocks of an impervious nature, the others are porous.

Rain falling upon such a locality as this will sink into the ground at all those places where the porous rocks come to the surface, and will meet with no obstacle to its passage until the beds of impervious material are reached, and along the surface of these it will collect. Further, an inspection of the figure shows that the impervious beds extend to a height on the right considerably higher than the points *s′*, *s*. Since water collects all along the line of junction of the porous and impervious beds, its

level on the right will be much higher than when at the points above named, and this will cause a constant force tending to make it flow at these points where springs occur, that is, at the fault or joint.

Artesian Wells are artificial springs. They are only possible where the rocks are arranged in a manner more or less as shown in Fig. 121, which is drawn to give an idea of the way the rocks lie round London. The basin-like character of the rocks is very much exaggerated so as to exhibit the arrangement on which the possibility of such a well depends. Near the surface are beds of clay, known as the *London Clay*; then follow beds known as the *Lower London Tertiaries*; they are largely made up of porous sands, but thin layers of clay occur

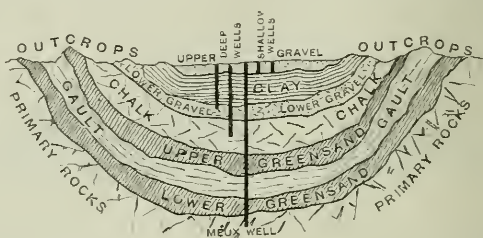

FIG. 121.—Showing the principle of an Artesian Well. The basin-like form is much exaggerated.
From the *Leisure Hour*.

at different levels. These clayey strata being impervious, serve to retain the water which sinks down into the sands, and thus water gets stored up there. If a boring is made through the overlying London Clay down into these sands and gravels, the water which has collected there obeys what we have seen is a natural property and seeks its own level, and being much higher near the outcrops of these lower beds, the water flows out at the boring and rises to this height, or as high as the water has collected in the sands. In the diagram borings are shown penetrating the lower beds; some of these are of chalk, which is remarkable amongst other things for the large number of crevices which it contains, and in these the water collects in a manner which cannot, however, be predicted, since the cracks follow no definite order, but if one of the numerous fissures be

struck by the boring, the supply of water from the outlet at the surface is very much augmented.

Wells of this kind are called *Artesian* wells, from the name of the French province Artois, where they were first constructed.

Rivers.—Part only of the rainfall of a district sinks into the ground and gives rise to springs, another larger portion flows over the surface, collecting into runnels, which continually unite, until at last a stream is formed. It is by the union of streams of this kind, together with those which have their origin in springs, that rivers are formed. Rivers can thus be regarded as the surplus rainfall running off to rejoin the ocean, whence it was originally derived. In addition to this, however, as has been seen, rivers contain a large amount of mineral substances dissolved, which being continually added to the oceanic waters, maintains their saltness. And not only are dissolved materials thus removed from the land by rivers, but also a large amount of suspended matter, which is hurried forward by the force of the moving water, and concerning which more will be said later.

Terms used in describing Rivers.—It will perhaps be desirable to first explain the terms which are in common use in describing a river. The student can think of any important river of a sufficient length to include samples of all the different kinds of country met with, but it will be best for our purpose to take an imaginary river starting high up in some mountain range. The commencement of the river is called its *source*; this may be at the foot of a glacier bordering the snow-line, where the temperature is sufficiently high to cause a constant melting of the snow or ice; or it may arise from a spring, marsh, or lake, in all of which cases it is often difficult to locate the exact spot where the river begins. Indeed, speaking generally, we may say that less is known of the source than of any other part of rivers. The river empties itself into the ocean at its *mouth*, and proceeds from its source to its mouth along the direction of its *course*. If we stand at any spot along the course of a river and look in the direction of the mouth, that is, along the direction in which the water is flowing, the bank on the right is spoken of as the *right bank*, the other as the *left bank*.

The water of a river represents the drainage of a certain tract of country, and a name is given to this area; it is known as the *river basin*. The highlands dividing one river basin from another constitutes a *water-shed*.

The course of a river is often divided into three portions, viz., the *upper*, *middle*, and *lower* courses. The upper refers to that part which flows down the steep mountain slopes, and is often called the mountain-track, and is characterised by its *waterfalls* where the

water drops a considerable height from one ledge to the next; by its *rapids*, where the river's waters are held between narrow confines, and by its *cascades*, which mean simply successions of waterfalls.

The middle course, or valley track, extends for a greater fraction of the whole length of the river than either of the other divisions. It differs chiefly from the higher portions in being navigable. The decrease in the steepness of its channel is marked by a corresponding diminution in its velocity, and it is throughout this part of its journey to the sea that it is joined by other, oftentimes equally important, branches called *tributaries*. The place where two such rivers join one another is called their *confluence*. It will depend upon the rate at which the steepness diminishes as to what is the character of the river's course. If it flows over a country where the altitude very gradually decreases, it will wind about, seeking the place of greatest slope, and will have a long, meandering course. On the other hand, should there be a regular fall towards the sea its path will be straighter, though even then its direction will be influenced by the hardness or otherwise of the rocks over which it flows.

The lower reaches, sometimes called the plain-track, are terminated by the river's mouth. The velocity of the water has been gradually diminishing throughout its course until here it is least. This means an equivalent lessening of its carrying power, which is made very evident by the deposition of the heavier materials brought along by the river, until by-and-by, when the mouth is reached, most of the gravel, sand and mud which it has still been able to hold in suspension are here thrown down; the mud being the lightest is carried longest. The accumulation of such material at a river's mouth often gives rise to a *delta*. Sometimes, however, when the alteration in the velocity of the river is more sudden, due to its abrupt contact with the comparatively still waters of the ocean, a *bar* is formed.

The Velocity of Rivers varies at Different Parts.—This has been incidentally referred to already in enumerating the characteristics of the different parts of a river. The rule clearly is that *the velocity is greatest where the slope is most.* But not only is there this variation in different parts of the river's course, but also in different points of any cross-section of the river. The water nearest the banks and bed of the river has its velocity impeded by the resistance of friction which they offer; therefore anything which lessens the friction will increase the velocity of the current, and it is for this reason that the river rushes with so great a speed through the channel of a gorge where the rocks are hard and smooth. The most quickly moving part of any stream will be a comparatively small part in the middle.

Work of Rivers.—The work done by rivers is of two

kinds, viz., *chemical* and *mechanical*. The former is very much less important than the latter, but is at the same time very considerable. The river has the same solvent power which characterises water under all circumstances, and where the river runs over very soluble material, such as limestone, which, as we have seen, dissolves with ease in any water containing carbon dioxide, as river water does in considerable quantity, the effects of the river's solvent action are most marked, tunnels and ravines being in time eaten out.

Mechanical Work of Rivers.—This part of a river's activity can best be considered as consisting of three sorts of work. 1. The transportation of loose materials such as mud, sand, gravel, and larger stones from one place to another. 2. The erosion or wearing away of the rocks over which the river passes by the friction of the materials it carries. 3. The deposition of the substances named in lakes and in the sea, thus forming new beds of rock which in time become hardened to form new geological formations.

Transporting Power of Rivers.—In addition to the fine material held in suspension by its water, the river moves a considerable amount of coarser fragments along its bed. As these move along, the persistent rubbing against the channel and one another which they undergo causes them to get gradually smaller and smoother, eventually giving rise to the "water-worn" appearance which characterises the pebbles at the bottom of a stream or river. The suspended material causes too great a degree of turbidity in the water for the more slowly-moving layer on the bed of the river to be visible. But in certain rivers, such, for example, as the Rhine above Bonn, it is possible, by applying the ear to the bottom of a boat drifting down the stream, to hear the grating of the stones against one another as they are pushed along over the rocky channel.

As would be expected, the carrying power of a river depends, not only upon the volume and velocity of its current, but also upon the size, form, and density of the sediment. But it is not the velocity of the stream as a whole, of which we have spoken on p. 268, but the rate at which the river is able to overcome the friction of its channel that must be taken into account in forming an estimate of the river's capacity in this direction. It must also be borne in mind that the specific gravity of the rocks is

not an exact index of the amount of resistance which has to be overcome by the current, since they lose from a half to a third of their weight in the air when they become immersed in water.

In addition to materials such as we have described, rivers often carry down towards the sea huge masses of vegetation in which the remains of land animals may be buried.

The actual amount of such material, whether inorganic or organic, carried seawards by a river depends upon the amount of rainfall and other circumstances, which vary from time to time. More may be taken down in one day during a flood than the river would carry in months under ordinary conditions.

Excavating Power.—By far the greatest part of the work of erosion is done by the fragments held in suspension and pushed along the bed of a stream.

In those cases where eddies are produced in the course of a river the loose fragments, to which constant reference has been made, are whirled round and round and produce hollows, called *pot-holes*, in the river's bed.

The most important factor determining the extent to which this wearing away goes on is, however, the nature of the rocks

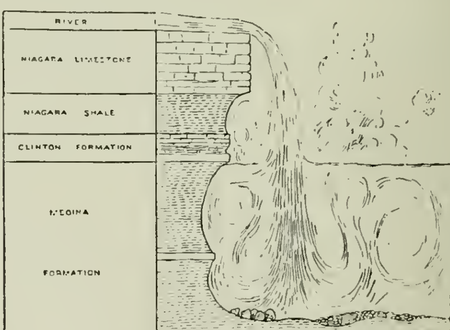

FIG. 122.—Section of the Rocks at the Horse-shoe Falls. (Gilbert.)

over which the river flows. Hard rocks will be excavated to a much smaller extent than soft ones. One of the best examples of this is afforded by the renowned falls of Niagara, which are

situated between Lake Erie and Lake Ontario. The river flows from the former lake to the latter and passes over a series of beds arranged as shown in Fig. 122, which shows a section of the rocks at the Horse-shoe Falls. It is at once seen that the bed of the river is formed by the hard Niagara limestone which

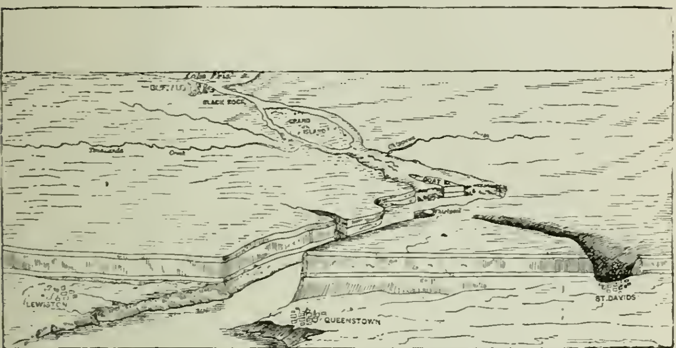

FIG. 123.—Bird's-eye view of the Niagara River. (Gilbert.)

overlies the softer shales and sandstone. The water as it rushes over the fall dashes against the underlying softer rocks and wears them away at a great rate thus undermining the limestone, which eventually, by its own weight, falls into the rapids below and is washed away. That this kind of action has been going on for some time, and at a rapid rate, is clearly shown from the following considerations. At Queenstown, seven miles distant from the Horse-shoe Falls, the limestone mentioned above forms an inland cliff or *escarpment*, and a deep trench extends from this place back to the falls. An examination of the nature of the gorge makes it abundantly evident that the river has by a continued action in the manner described eroded a channel seven miles in length. Careful observations made from time to time give as the yearly amount of erosion at these particular falls 2 feet 2 inches. From 1848 to 1890 no less an amount than 275,400 square feet of rock have been washed away (Fig. 123).

We must not leave this part of the subject without some reference to the magnificent instance of river erosion which is

afforded by the *cañons* of Colorado. These cañons are gorges with nearly vertical sides cut out of horizontal beds of soft rock by the river found at the bottom of the ravine. The rocks on either side of the natural cutting correspond exactly, and if there were any doubt of the horizontal nature of the strata, it would be at once set at rest by the consideration that inclined beds would, by the continual tendency to slip, eventually slide down into the river, thus effectually destroying the remarkable perpendicularity which characterises these cañons (Fig. 124).

Deposits formed by Rivers.—To fully understand the conditions under which deposition takes place, it is only necessary to bear in mind the circumstances upon which the power of transportation depends. We have seen that an increase of velocity is accompanied by an augmentation of carrying power, and in consequence, if for any reason the velocity becomes diminished, the river will no longer be able to bear along as large an amount of sediment, and some of it will be deposited. Naturally, too, the heaviest particles will be left behind first, the lightest material being still held in suspension and only deposited when the velocity has been reduced to almost nothing. The question resolves itself, then, into this, Under what circumstances is the velocity of a river diminished? This may happen in a great variety of ways.

(1) *By the decrease in velocity which accompanies the passage from the mountain track to the valley track* (p. 267).

(2) *When a river overflows its banks as the result of a flood, which may be caused by excessive rainfall, or by a sudden melting of the snows near its source. A deposition of its suspended detritus takes place, forming a deposit of fine silt and mud.* Each successive flood adds to the amount until, after a time, the volume of the river at its flood is not enough to overflow its raised banks.

Side by side with the processes which have just been named there is a continuous winding about of the river owing to the inequality of the hardness of the several portions of its banks, the softer parts being eroded more rapidly than others.

(3) *When a river enters the still waters of a lake, causing a deposition of material at the place where the stream enters the lake.* The tongue of alluvium thus thrown down forms a delta.

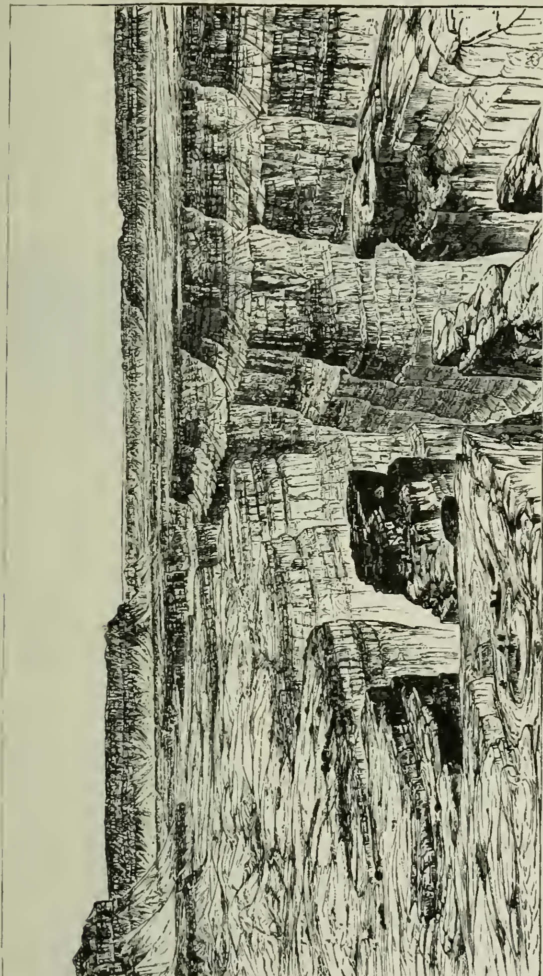

FIG. 124.—Grand Cañon of the Colorado. (Holmes.)

The materials brought down in this way will gradually, it is clear, fill up the lake into which the river flows. This has happened in some cases, the site of the lake being occupied by a plain of alluvium, in which fresh-water shells are deposited.

(4) *By rivers flowing into the sea, resulting in the formation of bars in some cases or, as in the greater number of instances, of deltas, on a grander and larger scale than those formed in lakes.* In order that a delta of this order may be formed several conditions must hold good. The coast at the mouth of the river

FIG. 125.—The Delta of the River Nile.

must be sheltered; there must be an absence of currents and tidal movements in the waters of the sea into which the river empties itself; and, finally, the velocity with which the river pours into the sea must not be sufficiently great to carry the suspended material far away from the coast, *i.e.*, the materials must be deposited in the sea more abundantly than they are carried away by the movements they meet with in the sea. Fig. 125 shows the delta which has been thrown down by the River Nile. The area enclosed by lines joining Cairo, Damietta, and Rosetta is in the shape of a triangle, and it is from the fact that the shape of the Greek letter Delta (Δ) is also triangular

that deposits of this kind are called "deltas." From an examination of the nature of the deposits forming the country between Cairo and Damietta, it is clear that at one time the Nile entered the sea at the former place, and that the alluvium which extends from it to the Mediterranean, a distance of 100 miles, has been gradually thrown down by the river. The distance from Rosetta to Damietta is ninety miles, but from the extreme mouths of the Nile, as shown by the dotted line in the figure, the distance is more nearly 200 miles. Borings have been made in the Nile delta, and have revealed the fact that the alluvium reaches to a depth of 120 feet. The student will be able to form some idea of the immense amount of erosion in the upper parts of the river's course which this represents, and will begin to appreciate the necessity of some compensating influence to prevent the whole of the land being worn down to the sea-level, and to which his attention will be directed later.

In the case of certain other of the large rivers of the globe, deltas of still greater magnitude have been deposited, and amongst these our space only permits of a mention of the Mississippi, the Ganges, and the Brahmaputra.

Tidal Rivers.—In the case of those rivers which flow into a long narrow opening of the sea, as, for instance, the Thames and Severn of this country, the movements of the salt waters of the ocean will influence the height of the waters of the river, the distances from its mouth varying in the case of different rivers. One of the most familiar of these oceanic movements is that known as the *tides.* It is sufficient for our purpose to regard the tides as due to great waves which travel round the earth as it rotates, and caused by the differential attraction of the sun and moon upon the waters of the globe, and which are experienced at all places on the coast, causing the phenomena known as high and low tide. In the case of the Thames the influence of the tides is felt as far up the river as Teddington, nineteen miles from London Bridge. Above Teddington the water flows steadily seawards throughout the day, while below this place during one part of the day the direction of flow is *up* the river and during the other *down.* The resultant motion of the waters of the Thames estuary effectually prevents the formation of a delta at the river's mouth, though there is a continual deposition going on which takes place farther out at sea, but in an irregular

fashion, of the nature of shoals. Often the retarding effect on the inflowing tide upon the outward movements of the river's water causes a deposit of the nature of a *bar*, to which reference has already been made. In other cases the collision of these two currents, especially where the channel is narrow, as in the case of the Severn, causes the water to be forced up to a considerable height constituting a *bore*.

Glaciers.—We have seen that above a certain height on lofty mountains the snow never melts. The line above which snow always exists is called the *snow-line*. It is from this snow that glaciers are derived. The continual accumulation of snow naturally subjects that at the bottom of the heaps to a great pressure, which eventually completely changes the character of the accumulation. As the snow becomes more and more pressed upon by the weight of the overlying masses it loses its granular nature. The particles gradually cohere, forming a firmer mass, called *nevé* or *firn*, which represents the intermediate stage between snow and ice. Finally, the increased pressure lower in the mass causes the formation of a compact blue ice which slowly moves down the mountain slope as a glacier.

It is not difficult to understand why such a movement of the glacier should take place when it is remembered that the whole process is followed out on the slope of a mountain down which any mass would naturally fall if quite free to move. It is true that the force of adhesion between the ice and sides of the valley has to be overcome, but the force from behind, caused by the weight of the ever-increasing mass of snow, is quite great enough to overcome this adhesion.

Properties of Ice.—To understand the characteristics of glaciers, something should be known of the properties of ice.

§ EXPT. 202.—Show that a block of ice floats in water with about nine-tenths of its bulk submerged.

§ EXPT. 203.—Illustrate regelation by pressing two pieces of ice together in a basin of water, and by supporting a block of ice on two stools, and suspending from it a heavy weight attached to a wire. The wire will gradually cut its way through the ice, which will close up and become united behind the descending wire.

§ EXPT. 204.—Demonstrate the difference in behaviour of ice in small fragments and great masses by means of pitch, sealing-wax, and glass, especially noticing the effects of changes of temperature. Rest a stick of sealing-wax on two supports, and show that it becomes gradually curved by its own weight.

Glaciers are Rivers of Ice.—Just as rivers can be looked upon as the drainage of the rainfall in a district, so glaciers are to be regarded as a system of drainage by which the snow-fall above the snow-line is removed. But the similarity between the two does not end here. Glaciers move from high levels to lower in the same manner as rivers, though, as they are so much less fluid, the rate of movement is very much smaller. Whereas the rate of flow of a moderately quick river is about one and a quarter miles per hour, and of a torrent about eighteen or twenty miles in the same time, a glacier moves only a few feet or inches in a day. Thus the Mer de Glace of Chamouni has an average rate per day throughout the summer and autumn of twenty to twenty-seven inches in the centre, and from thirteen to nineteen and a half near the sides. The glaciers of Greenland are more rapid, however, that of Jacobshavn on the west coast has a rate varying from forty-eight to sixty-five feet in the twenty-four hours. The difference in the rate of motion of the glacier at the centre and at the sides, noticed in the case of the Mer de Glace, is characteristic of glaciers and constitutes another likeness between them and rivers. In both cases where the friction to be overcome is greatest the velocity is least, and this will clearly be at the bottom and sides.

Proofs of a Glacier's Motion.—This variation in the motion of different parts of the glacier can be demonstrated in the following ways :—

(1) The fissures across the glacier (crevasses) are curved, the curve being convex towards the valley.

(2) The heap of rubbish at the foot of the glacier (terminal moraine) assumes the same horse-shoe form.

(3) If a row of stakes be driven into a glacier in a straight line, after a time the middle ones will be seen to have travelled further down the valley than those at the sides.

Behaviour of Glaciers in Moving Downwards.—The exact causes producing the movement of a glacier cannot be said to be fully known. It has been suggested that ice behaves like a very viscous liquid, and slowly flows in the manner we have described on p. 276 ; but other authorities maintain that there is a continual melting and breaking of the ice going on, which is followed by the freezing together or regelation of the separated parts, and that this is sufficient to account for the

small amount of yielding which is experienced. When a glacier moves valleywards, it has sometimes to travel over a very uneven floor, and some part may get wedged up against an outstanding projection and be prevented from moving, while the upper parts, being still acted upon by the weight of the accumulated snows above and being free to move, slide over the impaled portion. This will interfere with the regular movement of the glacier, producing something comparable to an eddy.

A sudden drop in the slope of the mountain side, which would in the case of a river produce a waterfall, will cause a break in the glacier. This fissure may in the first instance be nothing more than a crack, but the onward passage of the lower portions will by and by result in the formation of a wide gap known as a *crèvasse*. These crevasses sometimes reach quite to the bottom of the glacier, but whether they do or not there is always a tendency for the pressure, which is felt all round, to efface the rent.

The glacier will continue its existence and downward motion until the temperature becomes great enough to melt the ice as it arrives, when it will give place to a stream of muddy water which may, as we have seen, be the source of a river. It will be evident to the student that a prolonged addition to the snow accumulation towards the summit of the mountain will increase the supply of ice at the valley end and the amount of heat will of necessity have to be greater to effect the liquefaction of the ice, and this increased amount of heat can only be obtained lower down, or the glacier will experience a prolongation. A diminution in the supply of snow will have the contrary effect.

Work done by Glaciers is only Mechanical.—From its nature the glacier can perform no appreciable amount of chemical work. But the work of a mechanical nature which it accomplishes is very important, and can be considered under two heads—(1) its carrying work; (2) the erosion it effects.

The work of transport is performed in a different way from rivers, for most of the detritus is carried upon the surface of the glacier. The solid ice cannot hold material in suspension, though frozen into its mass will be fragments of rock which were disseminated throughout the snow from which it was formed. Corresponding to the larger materials which are pushed along the bed of a river, there is in the case of the glacier a certain

amount of detritus at the bottom which has for the most part got there by tumbling down crevasses. This rubbish which accumulates on the surface of a glacier is known as *moraine* stuff; it is not irregularly distributed, but arranged more or less definitely along the sides and middle, constituting *lateral* and *median moraines* respectively. The median moraines are the result of the union of two glaciers, for in this event the right of one and the left lateral moraine of the other will unite to form a

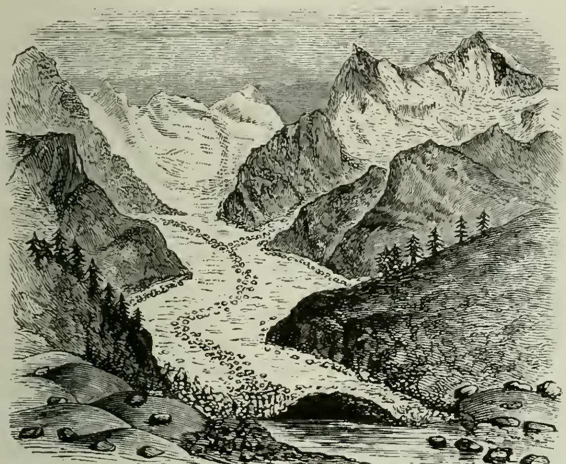

FIG. 126.—A Glacier on which can be seen Lateral and Median Moraines.

larger single median one. Should a glacier receive several tributaries there will be more than one median moraine formed, the number indicating the tributaries it has received (Fig. 126).

In travelling over uneven ground there will be a tendency for the detritus, which has reached the bottom through the crevasses, to accumulate in places where the projections, to which reference has already been made, occur. These accumulations constitute what are termed *moraines profondes*.

If for any cause a diminution in the volume of a glacier takes place some part of the lateral moraine will be deposited on the

side of the valley. This deposit often contains blocks of some size, and when these are left in such a stranded position they are spoken of as *perched blocks*. It is quite possible to mistake masses of rock standing in a similar isolated position, which have been left thus by the ordinary processes of disintegration, for perched blocks. An almost infallible way of distinguishing a perched block consists in a comparison of its nature with that of the beds on which it rests, for in the case of a block left by a glacier there is a complete dissimilarity between the two, whereas in other cases the block and the underlying formations will be seen to be of the same nature. In earlier geological times glaciers were much more widespread over Europe than they now are, and it is very common to meet with perched blocks far removed from any existing glacier, but about the manner of whose deposition there is no doubt.

A Glacier's Work of Erosion.—The earth and stones which often, as we have seen, find their way down crevasses to the bottom of a glacier become firmly frozen into its mass, and as the ice-sheet moves slowly down the mountain side these are ground against the rocky bed, becoming themselves characteristically smoothed and scratched, and also causing the same result upon the beds over which they pass. This polishing effect is so great that even the hardest rocks are grooved and striated. The motion of the glacier being generally regularly downwards, these scratches usually indicate the line of motion and stretch lengthwise down the valley (Fig. 128).

When by a general increase of temperature the glacier as a whole melts, its valley is seen to have assumed the form of smooth undulating prominences, in appearance not unlike the backs of dolphins as they appear at the surface of the water in which they are rolling. These rounded mounds are called *roches moutonnées* (Fig. 127).

The water formed from the local melting of a glacier collects on the surface and often finds its way down one of the numerous crevasses, carrying with it a considerable quantity of the moraine detritus. This water finally gets under the glacier, and in many cases, by the help of the stones it carries with it, erodes a kind of pot-hole, which is in some places spoken of as a *giant's kettle*. As was pointed out in describing the same sort of work in the case of rivers, the largest amount of erosion will be effected in

those cases where the rocks are soft. It is sometimes indeed sufficiently extensive to form considerable hollows, which on the retirement of the glacier often become filled with water, forming *tarns* or *lakes*.

Results of Glacial Action.—The student will readily perceive that it is quite possible to tell where glaciers have been

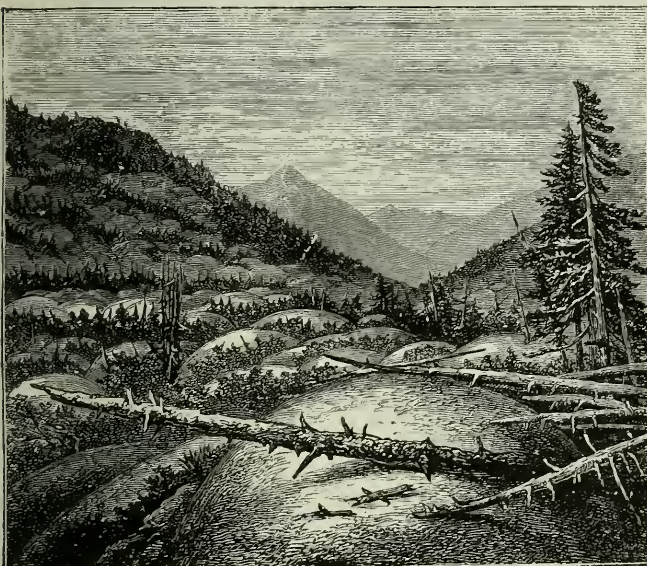

FIG. 127.—Roches Moutonnées Creek, Colorado. (Hayden.)

from the permanent record they leave behind. We can summarise the occurrences, the existence of which in any country can be taken as proof of the previous existence of glaciers.

(1) The heap of materials formed at the glacier's foot where it began to melt, which contains striated stones and is known as the *terminal moraine*.

(2) The smooth glaciated rocks which formed the bed of the glacier are unmistakable. The striations found thereupon are

more or less parallel, and show the direction of the glacier's flow (Fig. 128).

(3) Perched blocks often occur on what was originally the side

FIG. 128.—Glacial Striations at Kingston, Ohio.

of the glacier. They are quite dissimilar in nature from the rocks on which they rest.

(4) The material at the bottom of the glacier (moraine profonde) is strewn irregularly over the site of the glacier, and con-

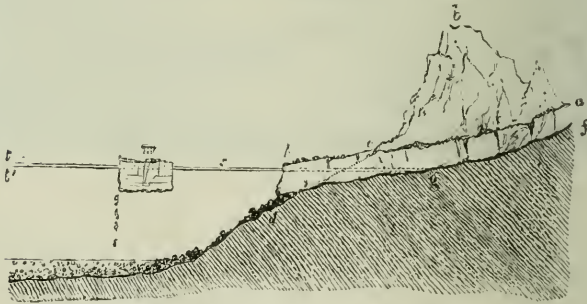

FIG. 129.—The Formation of an Iceberg.

tains characteristically marked stones, the mixture constituting *boulder-clay*.

Icebergs are broken off from Glaciers which reach the Sea in Polar Regions.—When a glacier in these high

latitudes reaches the sea-level, it moves on into the water, where parts get broken off and float away as *icebergs.* Evidently, then, the iceberg is frozen fresh-water, and was formed on land. We have already learnt that ice is lighter than water, its specific gravity being ·918 compared with water at 4° C. The ice consequently floats upon the water, and as its density is very near that of water, only about one-ninth of the iceberg is above the sea-level, the other eight-ninths being below. As the iceberg travels into warmer latitudes it gradually melts, dropping into the sea the materials which were frozen into it when it existed as a glacier. Icebergs are often of a great size, being sometimes several miles in circumference and rising to a height of two hundred feet above the water. They are rarely found more south than the 44th parallel of latitude in the northern hemisphere.

Chief Points of Chapter XVII.

Springs may be classified into—(1) surface springs, the flow of which is immediately dependent upon the rainfall; (2) deep-seated springs and artesian wells, the water of which is forced up from great depths by hydrostatic pressure.

A River is the surplus rainfall running off the land surface towards the ocean, whence it was originally derived.

The Velocity of a River increases with—(1) the slope of the bed; (2) the addition of more water, causing the river to rise; (3) a decrease in the breadth of the channel.

Work of Rivers.

Chemical | Mechanical

Transportation of materials

In solution | In suspension | Pushed along bed. (Active agents in excavation.)

In suspension: Deposited to form bars and deltas.

Sediment is Deposited when a river—(1) passes into a less inclined part of its track; (2) overflows its banks; (3) enters the still waters of a lake, or flows into the sea.

Conditions Favourable to the Formation of Deltas.—(1) A sheltered coast where the river enters the sea; (2) absence of currents; (3) the river must not possess sufficient velocity to carry the sediment far out to sea.

Tidal Rivers are those which ebb and flow like the sea, and have similar periods of high and low water. The tidal effect decreases from the mouth of a river upwards.

Glaciers are rivers of ice flowing from high to lower levels, and draining regions above the snow-line of their superabundant snow.

Work of Glaciers.

Transport of materials
- At bottom and sides
  - Producing
    - U-shaped valley.
    - Deep basins in soft rock.
    - Glacial striæ.
- On surface
  - Lateral moraine
  - Lateral moraine
    - Medial moraine
      - Terminal moraine.

Indications of Former Existence of Glaciers in a region are—(1) terminal moraine material; (2) glacial striæ; (3) perched blocks; (4) roches moutonnées; (5) moraine materials distributed over previous site of glacier.

Icebergs are not frozen sea-water, but masses of ice broken off from glaciers which reach the sea in polar regions.

Questions on Chapter XVII.

(1) Describe the mode of formation of—(*a*) a lateral moraine, (*b*) a medial moraine, (*c*) a terminal moraine, (*d*) a glacier table. (1896.)

(2) Give diagrams showing the ways in which surface springs and artesian wells are produced.

(3) What is a delta of a river? Explain how deltas are produced.

(4) It is said that "Glaciers are Rivers of Ice." Write what you can in support of this statement.

(5) Compare the work of a river with that of a glacier.

(6) Name some facts which show that glaciers once travelled over districts where they are not now found.

CHAPTER XVIII

THE EARTH'S SOLID CRUST.—IGNEOUS ROCKS

The Crust of the Earth.—The geologist calls that outer part of the earth which he can examine and study the *crust of the earth.* There are many reasons for believing that our planet was once at a very much higher temperature, at which the materials composing it could not exist in the solid state. In the beginning the earth was probably made up of vapours and gases, which as the earth cooled by radiating its heat into space, afterwards assumed the liquid condition, and this in its turn, on the outside at all events, gave place to the solid form. This solid layer formed a *crust*, as it were, round the still fluid interior. As more heat became radiated, more of the planet became solid, and this process is still going on. It is generally believed that all planets have passed, or will pass, through similar changes.

Rocks.—The materials which build up the crust of the earth are known to geologists as *rocks.* While, in common language, a rock is always regarded as something more or less hard and heavy, to the geologist there is no such restriction. Mud, sand, granite, chalk, are all called rocks, although they differ so widely as regards their hardness.

Minerals.—Rocks are built up of simpler component parts, called *minerals.* The old definition of a mineral contained in books on Geography will not do at all. It is not enough to speak of a mineral as something "dug out of the earth" or "got out of mines." For coal is got out of mines and dug out of the earth, and yet it is not a mineral but a rock. *A mineral is a natural substance, with a fairly definite chemical composition*

which does not vary from part to part of its mass. It was formed without the help of animals or plants.

Minerals, then, are simpler than rocks. Rocks are generally made up of two or more minerals, or, *a rock is an aggregate of minerals.*

Common Rock-forming Minerals.—The most abundant elements in the earth's crust given on p. 112 are combined together to form the common minerals. These minerals in their turn become associated with others to form rocks. It is necessary at this stage to describe a few of the commonest of the rock-forming minerals. In the order of their abundance the most common of these minerals are :—1. *Felspars.* 2. *Quartz.* 3. *Micas.* 4. *Talc.* 5. *Calcium and Magnesium Carbonates.* 6. *Amphiboles*, e.g., *Hornblende.* 7. *Pyroxenes*, e.g., *Augite.* 8 *Diallage.* 9. *Olivine.* 10. *Various other substances.*

Felspars.—These minerals, for the class includes several, are all of them silicates, *i.e.* (p. 135), salts formed by the combination of certain basic oxides with silicic acid. Or, they can be regarded as formed by the union of binary compounds, viz., basic oxides and silica. They can be scratched, but not easily, with the point of a knife. They are generally white, or of a pale colour. The various members of the class are differently named, according to their chemical composition. The most typical are *Orthoclase*, *Albite*, *Anorthite*.

Orthoclase is a felspar made up of two silicates combined together ; these are aluminium silicate and potassium silicate. We can express this differently and say that orthoclase is a double silicate of aluminium and potassium. It is called *potash felspar.* It helps to build up many of the igneous rocks, *e.g.*, granite.

Albite is a felspar containing sodium in the place of potassium, and is known as *soda felspar.* It is not as abundant as orthoclase, but, like it, occurs in igneous rocks.

Anorthite is a felspar containing calcium in the place of the potassium and sodium of the last two minerals. It is sometimes spoken of as *lime felspar.* It is not an abundant mineral. It occurs in igneous rocks, such as the lavas of Vesuvius.

Many other felspars are known, some of them more abundant than the examples we have given. But they can be regarded as mixtures in varying proportions of the types we have described. The most important are *Oligoclase* and *Labradorite.* All the

felspars can be divided into two classes, according to the kind of crystals they form. Orthoclase forms one class called the *Orthoclastic felspars*, while the est constitute the division of the *Plagioclastic felspars.*

Quartz.—We have already fully described this mineral in another part of the book (p. 138). We have there learnt to regard it as a crystalline variety of the binary compound silica. It is a very common constituent of a variety of different kinds of rocks. It is found in sand and sandstones ; in igneous rocks,

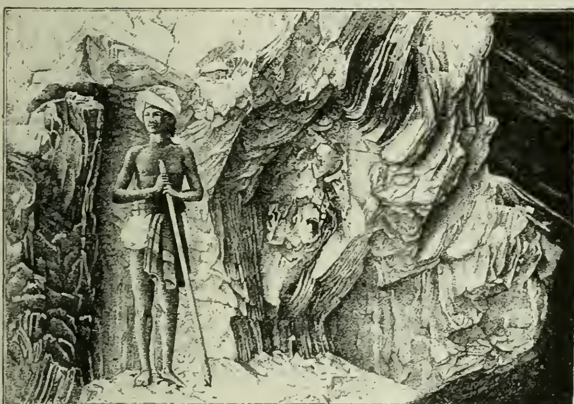

FIG. 130.—Exposure of Mica at Inikurti, Nellore District, Madras. (Geological Survey of India.)

like granite ; as well as in certain changed or *metamorphic* rocks, like quartzite.

Micas constitute a class of minerals. They resemble the felspars in being silicates. We shall only describe two members of the class, viz., *Muscovite* and *Biotite.*

Muscovite is, like orthoclase, a double silicate of aluminium and potassium, though it contains the elements in a different proportion. Muscovite is most remarkable for the ease with which its crystals can be split into plates. These plates, which are thin and fairly transparent, are often sufficiently large to be used, as in Siberia, instead of glass for windows. It is com-

monly used in constructing lanterns and stoves. It is a soft mineral, the finger-nail often being hard enough to scratch it. In colour it is generally light, never being darker than quite a light brown. It occurs with quartz and orthoclase in granite. Fig. 130 shows some naturally occurring Indian muscovite.

Biotite is more complex in its chemical composition than muscovite. It is composed of a variety of silicates, viz., those of magnesium, potassium, iron, and aluminium. The iron present gives it a much darker colour than muscovite. It is known of colours varying from dark-green to black. Like muscovite, it easily splits into plates, which are not commonly very large.

Talc.—Muscovite is often commercially known as Talc, but such a name is very improper, since talc is a definite mineral which we have now to describe. It resembles the micas in being easily divided into plates. It is a silicate of magnesium which has combined with the elements of water or it is a hydrated silicate of magnesium. It is the softest of all minerals, and can easily be scratched with the finger-nail. It is known in a more massive form as *steatite*.

Carbonates of Calcium and Magnesium.—Next in order of abundance come the minerals which are carbonates of either calcium or magnesium or both. Those made up of carbonate of calcium are *calcite* and *aragonite*, which differ from one another only in their crystalline form. Calcite is also known as *Iceland spar*, *Calc-spar*, and by other local names. Calcium carbonate occurs more or less pure in the earth's crust in a great variety of forms, such as *chalk*, *limestone*, *stalactites*, *stalagmites*, *travertine*, &c., and since some of these have been formed with the help of animals or plants, we must defer their consideration, because such forms are not included under our definition of a mineral.

Calcite is generally quite transparent and somewhat resembles quartz, from which it can be distinguished by its inferior hardness. It is easily scratched by a knife, while quartz is unaffected. It is what is called a *doubly-refracting* substance. If a clear crystal of Iceland spar be placed upon the page of a book and the print viewed through it, two images of each word will be seen.

The carbonate of magnesium by itself makes up the mineral *magnesite* which is used in the manufacture of Epsom salts. The carbonates of calcium and magnesium together form *dolomite*

or *magnesian limestone*, which constitutes a common building stone. Dolomite was used in building the Houses of Parliament at Westminster.

Amphiboles and Pyroxenes. — The most abundant representatives of these classes of minerals have already been named. They are *Hornblende* and *Augite* respectively. All these minerals can be regarded as intimate mixtures of silicates of calcium, magnesium, and iron, and are often regarded as important members of the group of *ferro-magnesian silicates*, to distinguish them from those silicates which contain aluminium and some alkaline base, like those already described, and which are said to constitute the *alumino-alkaline silicates.* Since these amphiboles and pyroxenes contain iron, they are generally more highly coloured than the felspars and other alumino-alkaline silicates, as well as being much heavier. In this place it will only be possible to describe the typical members of what is a very important and extensive class of minerals.

Hornblende, being the most important member of its class, is often called *amphibole.* Its chemical composition is that given above, and is the same as augite. It is usually found when in more or less perfect crystals as elongated prisms. Though it has the same composition as augite it can easily be distinguished from this mineral, since its physical properties are different, *e.g.*, the shape of the crystals, its behaviour with reference to light when examined under the microscope, and so on. Several varieties are known. *Tremolite* is white hornblende and contains comparatively little iron. *Actinolite* or green hornblende contains more iron than tremolite but less than common hornblende. *Asbestos* is a fibrous variety which conducts heat very badly.

Augite, sometimes called *pyroxene*, generally occurs in the form of short stout crystals. The colour which the mineral assumes depends, as in the case of hornblende, upon the amount of iron present. Those varieties containing less than the average amount of iron are green and known as *Diopside.* Augite is not in so permanent or stable a condition as hornblende, and hence there is a constant tendency for augite to assume the form of hornblende. An intermediate stage in this process is found in the mineral *Uralite*, which has the outward form of augite but the molecular constitution of hornblende.

Some of the other ferro-magnesian silicates are *Enstatite*, *Bronzite*, *Hypersthene*.

Diallage can be regarded as a more or less altered form of augite. It only occurs in those rocks which were formed at some distance from the earth's surface, such as gabbro. Every gradation from common augite to diallage is known. Diallage exhibits what is known as a *Schiller appearance*, due to the presence of parallel lines on the crystals, which cause the light to be reflected in a peculiar manner.

Olivine is a double silicate of magnesium and iron, which occurs in rounded grains in certain igneous rocks such as basalt. It is easily decomposed, passing into *serpentine*. It is sometimes used as a jewel, when in larger masses being known as *Chrysolite*.

Various other Substances.—There is an almost infinite variety of minerals, which, severally occurring in small quantities, fall to be described here. The consideration of them belongs to Mineralogy; we must be content to refer the reader to what has already been said (p. 137) about *Magnetite*, which is the most ubiquitous of all minerals, and Rock-salt, which has been described under binary compounds.

Rocks

Division into Classes.—Rocks can be classified in many ways. The plan generally adopted, which for our purpose is best, is to divide them *according to their mode of formation*. According to this method we obtain three chief subdivisions :—

(1) Those which have been in the liquid condition as a result of the high temperature to which they have been subjected. They are known as *Igneous Rocks*. If they have cooled quickly, at or near the earth's surface, they are called *Volcanic*; if slowly, deeper down in the earth's crust, *Plutonic*. The rocks between these limits are often called *Dyke Rocks*.

(2) Those which have been once sediments in water, and being deposited in the order of their specific gravities are arranged in layers or strata. These are variously known as *Sedimentary*, *Aqueous*, or *Stratified* rocks.

(3) Those which have been changed or altered from one of the two classes named and called *Metamorphic*.

Classification of Igneous Rocks.—The first of the divisions into which we have divided rocks is further broken up into simpler classes. This can be done in many ways. First, there is the division into Volcanic and Plutonic Igneous rocks which is given above, and which is illustrated in Fig. 131. Or, igneous rocks may be classified according to their chemical composition, the basis of the classification being the amount of silica which they contain. We thus obtain the following divisions :—

(i) Those igneous rocks containing from 66 to 80 per cent. of silica and called, from the chemical character of silica, *Acid Igneous Rocks.*

(ii) Those in which the proportion of silica varies from 55 to 66 per cent. of silica, called *Intermediate Igneous Rocks.* This class includes several subdivisions depending upon the predominant silicate present.

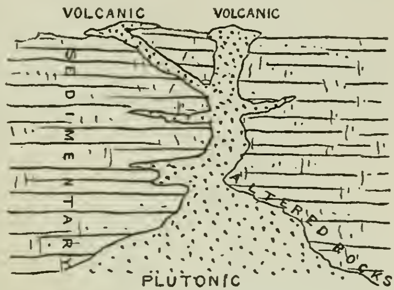

FIG. 131.—Volcanic rocks cool near the surface. Plutonic rocks cool deep down in the earth's crust.

(iii) Those containing from 45 to 55 per cent. of silica and called *Basic Igneous Rocks,* because the basic oxides are, as a rule, more abundant than the silica.

(iv) Those containing from 35 to 45 per cent. of silica and known as *Ultra-basic Igneous Rocks.*

The reader will at once understand that to find a rock's place in this classification a chemical analysis is necessary, and this can only be done in a laboratory. The geologist often wishes to define a rock in the field and hence it is sometimes convenient to divide igneous rocks *according to the minerals they contain.* In this way classes like the following are obtained :—(*a*) Igneous rocks containing Orthoclase ; (*b*) Igneous rocks containing Plagioclastic felspars and so on. Or, these rocks can be classified according to their structure, and the student will better understand this after the examination of rocks by the microscope has been described.

The student must clearly understand that if we adopt the classification of rocks according to their chemical composition we shall have volcanic, dyke, and plutonic rocks in each of the four divisions we have given. Thus, in the case of the acid rocks, the volcanic varieties are *Obsidian* and *Rhyolite,* the plutonic variety is *Granite,* while the connecting dyke rocks are known as Quartz-felsites. These all contain from 66 to 80 per cent. of silica and differ from one another in their structure only, which is the result of the rate at which they have cooled. The following table of igneous rocks makes this quite clear, and the student will have no difficulty in understanding that the rocks arranged

in vertical columns have very much the same chemical composition, while those in horizontal lines resemble one another in structure, but are quite unlike in composition :—

IGNEOUS ROCKS.

	ACID. Silica : 66—80 per cent.	INTERMEDIATE. *Sub-acid* Silica : 60—66 per cent.	*Sub-basic* 55—60 per cent.	BASIC. Silica : 45—55 per cent.
Typical Rocks contain	(i) *Quartz* (ii) *Orthoclase* (iii) *Mica* (*generally Muscovite*)	(i) *Orthoclase* (ii) *Hornblende*	(i) *Plagioclastic Felspar* (ii) *Hornblende*	(i) *Plagioclastic Felspar* (ii) *Augite* (iii) *Magnetite* (*often Olivine*)
VOLCANIC and GLASSY	Pumice Obsidian	Trachytic Pumice	Andesitic Pumice	Tachylite
VOLCANIC and HEMICRYSTALLINE	Rhyolite	Trachyte	Andesite	Basalt
PLUTONIC and consequently HOLOCRYSTALLINE	Granite	Syenite	Diorite	Gabbro

Plutonic Igneous Rocks.—The characters of this kind of igneous rock will be best understood by carefully considering an example. We shall take **Granite.**[1] The reader should procure a specimen and see the things to which attention is here called. The rock is entirely made up of crystals of different kinds, and a typical granite shows three sorts. First, there are large pink crystals of *Orthoclase*, which are too hard to scratch

[1] A piece of Dartmoor or Shap Granite is a good example.

with a knife. Secondly, silvery pieces of *Mica*, which can be split up into thin plates by inserting the end of the knife-blade Thirdly, small lumps of no particular shape and of a dull glassy appearance, on which a knife makes no impression. All the spaces between the crystals of Felspar and Mica are quite filled by these granules of *Quartz*. There is no arrangement about these minerals—they are mixed together anyhow.

Microscopic Characters of Granite.—A great deal more can be learnt by cutting a *section* of granite and examining it under the microscope. This is done by grinding a thin slice of the rock with emery powder and then polishing it by first rubbing it with emery flour, and finally on a Water of Ayr stone. The thin slice so obtained is cemented on a slip of glass with Canada balsam, and covered with a circle of very thin glass. The slice is now quite transparent, and when examined under the microscope it appears like Fig. 132. The quartz is clear like glass, and the grains are of no particular shape, they fill up the spaces between the other crystals; whereas the felspar has a clearly-marked outline, though, owing to chemical changes in it since its formation, it is cloudy. The long parallel lines along the pieces of mica show where the crystal would split to form the plates to which attention has been called. Rocks which are made up entirely of crystals, in the same manner that granite is, are called *holo-crystalline*. All plutonic rocks are of this nature. They are so because when liquid rock cools very slowly, under great pressure, as the plutonic rocks have done, the crystalline condition is always assumed. We can make all the information

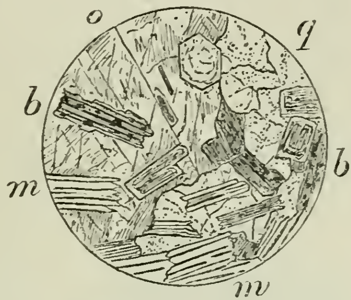

FIG. 132.—Microscopic Section of Granite. *o* is orthoclase; *q* is quartz; *m* is muscovite; *b* is biotite. From *Aids in Practical Geology*, by Prof. G. A. J. Cole. (Chas. Griffin and Co., Ltd.)

obtained up to this point into a definition thus: *Granite is a holo-crystalline aggregate of quartz, orthoclase, and mica. It is the plutonic variety of the acid igneous rocks.* There are many other kinds of granite, which each contain some other mineral instead of the mica, *e.g.*, *Hornblende-granite*, which contains hornblende instead of mica.

Syenite.—Similarly, *syenite is a holo-crystalline aggregate of orthoclase and hornblende. It is the plutonic variety of the sub-acid division of the intermediate rocks.*

Diorite *is a holo-crystalline aggregate of plagioclastic felspar and hornblende. It is the plutonic variety of the sub-basic division of the intermediate rocks.*

Many other kinds of syenites and diorites are known, but it would take us too far to describe them.

Volcanic Igneous Rocks.—These rocks have cooled more quickly than those just described. They were in most cases poured out of volcanic vents in the form of *lavas*, though most of the dyke rocks are best included under this head. If a piece of granite be melted in a suitable furnace and poured out on to the ground, the liquid rock loses its heat very rapidly, and soon becomes solid. But the new rock so formed is not a bit like granite, it looks just like a piece of bottle glass. We know it must have the same chemical composition as granite, and clearly there must be a new arrangement of the molecules, which build up the mass, to give rise to a rock with such different properties. *Obsidian*, which is mentioned in the table of igneous rocks, has just the appearance of the glassy mass above, and hence we come to the conclusion that obsidian was, like it, formed by the rapid cooling of a liquid rock, which, had it cooled very slowly, deep down in the earth's crust, would have given rise to granite. Thin sections of obsidian and other volcanic rocks, examined under the microscope, often reveal beautiful evidences of having

FIG. 133.—Fluxion or Fluidal Structure in Microscopic Section of a Rhyolite.

cooled while flowing. This is what is meant by the *fluxion* structure shown in Fig. 133.

Rhyolite, *Trachyte*, *Andesite*, *Basalt*, are all solidified lavas. They have cooled more slowly than obsidian, but more rapidly than granite. Their microscopic structure is intermediate between that of completely glassy rocks like obsidian and holo-crystalline rocks like granite. They are said to be *hemi-crystalline*, which means that they are composed of crystals or their constituent minerals and a more or less glassy ground-mass in which these crystals are imbedded. With the help of the table on p. 292 the student will have no difficulty in making definitions like the following ; andesite, for example :—

Andesite is a hemicrystalline aggregate of plagioclastic felspars and hornblende with a more or less glassy ground-mass. It is the volcanic variety of the sub-basic division of the intermediate Igneous Rocks.

Disintegration of Igneous Rocks.—The materials which build up the sedimentary rocks *can* all be derived from the breaking down, or decomposition, of igneous rocks, though we must not go so far as to say they have been. This disintegration of igneous rocks is brought about by atmospheric agencies. The changes which take place, though not identical with, are comparable to those happening in the case of granite, which we shall now describe. Typical granite contains quartz, felspar, and mica. The atmosphere, besides the elementary gases which it contains, is also partly made up of water-vapour and carbon dioxide. The effect of the atmosphere, or *weathering*, as it is called, upon quartz is insignificant. On felspar, however, it produces great changes. Orthoclase, as we have seen, is a double silicate of aluminium and potassium. The first result of the air's action is to separate these silicates. The aluminium silicate so formed is no further acted upon ; but the potassium silicate is decomposed by the carbon dioxide, giving rise to potassium carbonate and silica, which latter, it will be remembered, is soluble in water containing potassium carbonate in solution. In the case of those felspars containing sodium or calcium in the place of potassium (p. 286) the only difference will be that sodium or calcium carbonate will be formed instead of potassium carbonate. These changes, known as *Kaolinisation*, cause the cloudiness in the felspar crystals seen in the section or

granite, Fig. 132, where the decomposition is in its earliest stages.

The changes which the Mica (which is generally Muscovite) undergoes are small in amount but the same in kind as in the case of the felspars.

CHIEF POINTS OF CHAPTER XVIII.

Rock-forming Minerals.—Quartz, opal, orthoclase, albite, labradorite, muscovite, biotite, augite, hornblende, calcite, magnetite, olivine, serpentine.

Typical Igneous Rocks.—Granite, diorite, gabbro, rhyolite, andesite, basalt, obsidian, pumice.

GENERAL CLASSIFICATION OF ROCKS.

Rocks:
- igneous, have once been in liquid condition.
- stratified, have once been sediments in water.
- metamorphic, have been greatly changed from the original igneous or stratified condition.

CLASSIFICATIONS AND EXAMPLES OF IGNEOUS ROCKS.

Igneous	Volcanic	acid	pumice, obsidian
		intermediate	trachyte, andesite
		basic	basalt
	Plutonic	acid	granite
		intermediate	syenite, diorite
		basic	gabbro.

CHANGES UNDERGONE BY GRANITE.

GRANITE

- Quartz
  - No change, *Insoluble*, grains washed away.
- Orthoclase
  - Decomposed into Aluminium Silicate and Potassium Silicate
    - Aluminium Silicate No further change [*Insoluble*]
    - Potassium Silicate acted upon by Carbon Dioxide giving rise to
      - Potassium Carbonate [*Soluble*]
      - Silica [*Soluble*]
- Mica (Muscovite)
  - Changes very small, same in kind as Orthoclase

Note.—In case of other felspars, sodium carbonate or calcium carbonate is obtained instead of potassium carbonate.

QUESTIONS ON CHAPTER XVIII.

(1) Name five, *very common*, rock-forming minerals, and state what chemical elements are present in each of them. (1889.)

(2) Name the three great classes into which rocks are divided, and give an example of each.

(3) Name six common rocks.

(4) What minerals enter into the constitution of granite? Describe each of them.

(5) Name three igneous rocks, and state the characteristics of each.

(6) Classify the following into rocks and minerals: conglomerate, gneiss, obsidian, pumice, hornblende, serpentine, andesite, dolomite, quartz, and magnetite.

CHAPTER XIX

AQUEOUS AND METAMORPHIC ROCKS

Formation of Aqueous Rocks.—After the changes described at the end of the last chapter have gone on for some time, the solid mass of igneous rock completely changes its appearance. The crystals of felspar become decomposed into soluble and insoluble constituents, the former are dissolved by the rain, while the latter are carried away in suspension. There is no longer anything to bind the constituents of the rock together, and the insoluble quartz and little-acted-upon mica similarly become washed away. These materials are deposited again under suitable conditions, such as those described in the action of rivers, and give rise first to sediments, which, becoming hardened, produce the Aqueous rocks.

Siliceous Aqueous Rocks *are derived from the insoluble quartz, resulting from the decomposition of igneous rocks, and which becomes separated from the other products by the action of running water.* Names are given to different rocks formed in this way, according to the size of the constituent grains. The following are some of the chief :—

Sandstones are composed of very fine grains of quartz cemented together by different substances. Before this consolidation the quartz grains constitute a *sand.* We add a descriptive adjective to call attention to the nature of the cement, thus, *red sanastone* in which the grains of quartz are held together by a red oxide of iron ; *calcareous sandstones*, in which the cement is calcium carbonate. *Freestone* and *flagstone* are sandstones which

can be used for building and paving respectively. *Micaceous sandstones* contain flakes of mica along the planes of bedding.

Grits are made up of coarser pieces of quartz, say up to the size of a pea. The particles are sharp and angular.

Conglomerates are formed by the consolidation of *gravel*, in which the fragments are large and rounded or pebble-shaped. The cement is made up of finer grains.

Breccias or Agglomerates differ from conglomerates only in having angular fragments instead of pebbles.

EXPT. 205.—Powder a piece of red sandstone. Boil a little of the powder with strong hydrochloric acid in a test-tube. Notice the cement is dissolved. Filter and wash the grains of sand. Examine them under a low power of the microscope; notice they are rounded grains of clear quartz.

Argillaceous Aqueous Rocks *are derived from the insoluble aluminium silicate resulting from the decomposition of the felspars and other silicates of igneous rocks.* When the aluminium silicate is pure and combined only with water it constitutes *kaolin* or *Cornish china-clay*, but it is comparatively rarely so found, being generally mixed with varying amounts of lime, sand, oxide of iron, &c. This class of rock comprises the different varieties of *clay*, hence the name *argillaceous* (Lat., *argilla*, clay). Kaolin is white, but other clays are of different colours, depending chiefly upon the amount of the oxides of iron present. The chief varieties of this class of rocks are :—

Mud and *Silt*, which are names given to the fine loose materials which settle in quiet waters. When more compact and piastic they pass into clay.

Mudstone is hardened mud with no disposition to split up into layers.

Shale is hardened mud which can be divided into thin layers or laminæ. It is known as *carbonaceous shale* when it can be used as fuel.

Rocks formed from the Soluble Products of the Decomposition of Igneous Rocks.—From this point of view the chief soluble products of the decomposition of igneous rocks are silica and calcium carbonate. Both these compounds are insoluble in pure water. The first owes its solution to the presence of alkaline carbonates in the water, the latter to the dissolved carbon dioxide (p. 134). These dissolved materials give

rise to rocks as the result of two processes (*a*) chemical (*b*) animal and plant life.

Rocks formed by Chemical Means.—(1) *Those formed from calcium carbonate.—Travertine or Calcareous Tufa* is precipitated by springs which lose their dissolved carbon dioxide, which is necessary for the solution of the calcium carbonate, as they flow onwards. The carbonate, being insoluble in water alone, is deposited as soon as the carbon dioxide escapes.

Stalactites and Stalagmites.—The calcium carbonate of which these rocks is formed is not directly obtained from

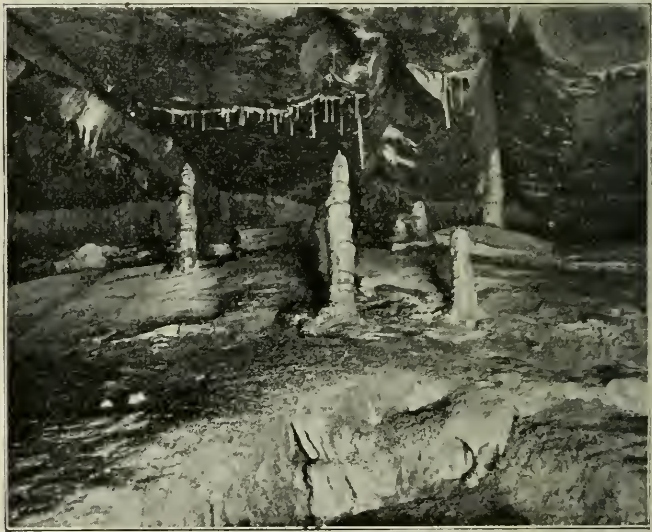

FIG. 134.—Stalactites and Stalagmites in Clapham Cave, Lancaster. From a photograph by Mr. George Fowler.

igneous rocks, it is true; but it is indirectly, as the reader will more fully understand when he has finished the present chapter. The streams traversing limestone districts become saturated with carbonate of lime. In their course they often trickle through crevices in the roofs of caverns which have been formed in the limestone by the same solvent power of this particular water.

The drop of water, which is thereby exposed on the roof, is subjected to evaporation, and the escape of the carbon dioxide and loss of water cause a slight deposition of carbonate on the roof, which is continuously added to by a constant succession of drops, until eventually beautiful pendants of calcium carbonate are formed, called *stalactites*, sometimes coloured by the presence of traces of iron oxide, and often having a wild profusion of forms (Fig. 134). Further evaporation of the water takes place on the floor of the cavern, giving rise to layers of the same chemical compound, called *stalagmites*.

Oolitic and Pisolitic Limestones, the former composed of small grains, the latter of larger ones of about the size of peas, are made by the deposition of calcium carbonate round minute grains of sand. The deposition takes place in concentric layers and their arrangement is best made out by the examination of sections under the microscope, which reveals the successive layers very plainly.

(2) *Those formed from Silica:—Sinter* is the rock resulting from the deposition of the dissolved silica in the water of hot-springs and geysers (p. 320). It is most probable that certain minute plants of the *algæ* group help in its formation and hence the proper place of this rock may be later, but it is still most often regarded as being chemically formed.

Other chemically-formed Rocks.—We have referred to these already as the consequence of supersaturation of the waters of the ocean and inland seas (p. 240). Beds of *rock-salt* (p. 140), *gypsum* (p. 140), *dolomite* (p. 288), are all formed in this way.

Rocks formed by the Aid of Animals and Plants.—These are sometimes spoken of as *organically formed*, or *organic* rocks.

The student should understand how plants and animals utilise the dissolved calcium carbonate and silica, and how the materials eventually come to build up rock-masses. These dissolved substances really form part of the *food* of the organism. After they have been assimilated by the animal or plant they are *secreted* from the fluids which circulate throughout the body of the organism by certain parts of the body called, in the case of an animal, *glands*, and so gradually build up their shells and other hard parts. When the organism dies it has no further use for its body, and the hard parts of it under favourable circumstances accumulate, sometimes in sufficient quantity to make masses of rock.

Organic Rocks composed of Calcium Carbonate.—Those formed by animals are much more abundant than those which plants build up. It will simplify the matter to first speak of the work of plants in this direction :—

(1) *By Plants.* Many minute seaweeds, which the botanist refers to as *algæ*, have the power of extracting calcium carbonate from sea-water. The carbonate sometimes helps to make up parts of the plant itself, at other times it is only deposited outside the organism, forming an incrustation. Small rounded lumps of calcium carbonate, called *coccoliths* when single, or

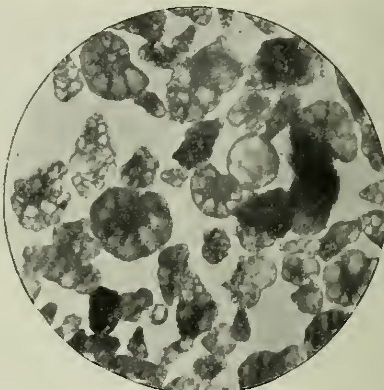

FIG. 135.—Foraminifera, from Saint Helena, Nebraska.

coccospheres when collected in masses, and formed in this way, occur on the floor of part of the Atlantic Ocean. They also occur in masses of chalk.

(2) *By Animals.* Many animals secrete calcium carbonate from the waters in which they live, and utilise it to build up their hard parts. All the so-called shell-fish do this. It is interesting to notice that the most abundant rock-masses have been built by the accumulation of the remains of the most insignificant animals. For our purpose, it will be most satisfactory to describe the chief rocks which have been thus formed.

Chalk is composed chiefly of the skeletons of very lowly

animals belonging to the group called *Foraminifera* the most commonly occurring member of the group being *Globigerina.*

Since these minute organisms flourish in abundance at the present day in the Atlantic Ocean, and the accumulation of their skeletons not only forms the white *ooze* found on the ocean floor, but also the chalk which makes up great rock-masses in the south-east of England as well as in other countries, we are justified in supposing, first, that chalk was formed at the bottom of a deep sea, and existed at the time of its formation as an ooze ; and secondly, that the ooze now being accumulated will some day be changed into chalk. Figs. 137 and 136 of globigerina ooze and a section of chalk respectively, as they appear under the microscope,

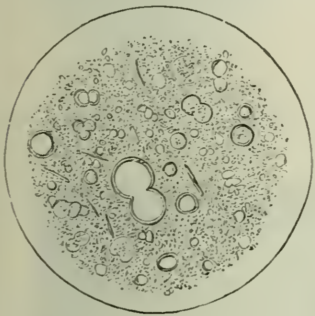

FIG. 136.—Section of a piece of Chalk. Magnified about 200 diameters.

FIG. 137.—Atlantic Ooze. Magnified about 220 diameters.

which are placed side by side, will do more to convince the student of the truth of this than a very large amount of description.

Coral.—It has already been pointed out, when speaking generally of organisms which extract either silica or calcium carbonate from the water in which they live, what the nature of *secretion* is. The coral polyp is perhaps the best instance of animals now living in the ocean which secrete calcium carbonate to form their hard parts. Fig. 138 shows the structure of coral polyps, and in it the septa, which divide each animal into parts, and which are hard and made of calcium carbonate, can be clearly seen. These organisms can only flourish in clear moving water, which is not below a temperature of 68° F., nor at a greater depth than about 120 feet below the surface. The polyps live in colonies, and the result of their existence and reproduction is

the formation of masses of coral like that shown in Fig. 139.

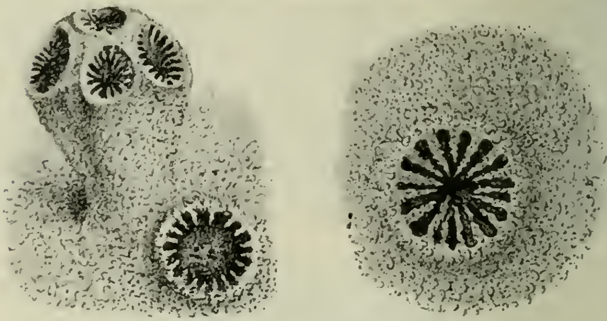

FIG. 138.—The Structure of calicles of Coral Polyps.

Reefs made entirely of the skeletons of these coral animals are sometimes very extensive, as, for example, the Great Barrier

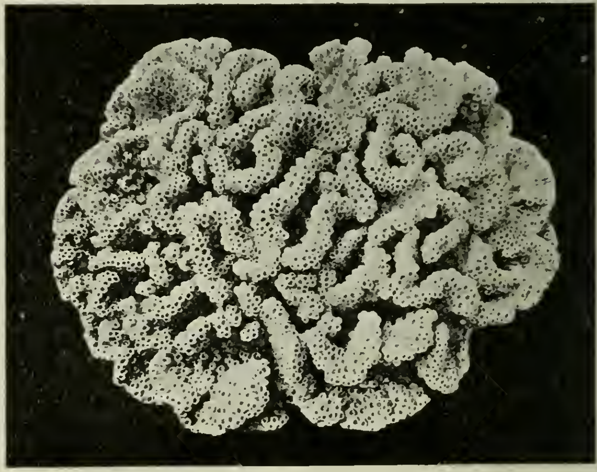

FIG. 139.—A Common Stony Coral—*Turbinaria peltata.*
(From the British Museum Catalogue.)

Reef of Australia, which has a length of upwards of 1200 miles along the north-eastern coast of that continent.

Limestone, also, is made up of calcium carbonate forming the remains of animals. It was secreted by them to form their hard parts.

There are many kinds of limestone formed by different animals, thus *encrinital limestone* is almost entirely built up of the jointed remains of animals called sea-lilies, belonging, as the zoologist would say, to the class of stemmed echinoderms (Fig. 140). *Shell limestone* is composed of shells large enough to be recognised by the naked eye. The animal remains which most commonly build up limestones are those of Polyzoa, calcareous Sponges, Corals (Fig. 139), Echinoderms, and Molluscs. The carbonate of lime is secreted by most of these organisms in the form of calcite, though by a few of them as aragonite, but when this is the case the aragonite gradually becomes calcite. *Coral-rock* is a limestone formed by the hardening of the mud which results from the action of the sea upon coral reefs.

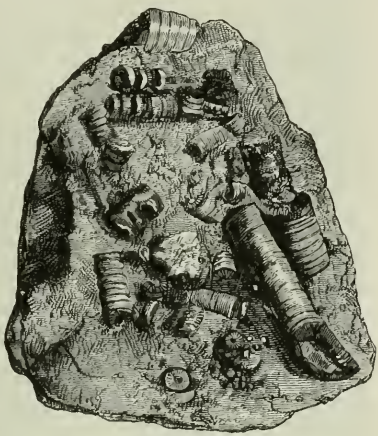

FIG. 140.—A Lump of Encrinital Limestone.

Organic Rocks composed of Silica.—(1) *Those formed by Plants.* These plants also belong to the Algæ group and are known as the *diatoms.* They are generally microscopic in size, but have existed in sufficient numbers to form, by the accumulation of their hard remains, beds of considerable thickness. They are made of the silica which the living diatom secreted from the water, either fresh or salt, in which it lived. At Richmond, in Virginia, beds of forty feet thick, and consisting entirely of diatoms, occur. *Diatomaceous earths* and *Tripoli powder* have been made in this way.

(2) *Those formed by Animals.* These silica-secreting animals, like the foraminifera already referred to, belong to the class of simplest animal structure known ; they are called *Radiolaria.* Their remains build up the *Radiolarian earths* which occur in

various places. A good instance is provided by the radiolarian earth of Barbadoes. Certain sponges, called siliceous sponges, have this power of extracting silica from the water in which they flourish. They utilise the silica to form the *spicules* which are commonly found associated with the remains of radiolaria.

Organic Rocks composed of the remains of Land Plants.—These make up what are sometimes called *Carbonaceous rocks.* The class includes *peat*, *lignite*, *coal*, *anthracite* and *graphite.* These will be described in order.

Peat is the first stage in the formation of coal. It has none of the characters usually associated with rocks, and is included here because it

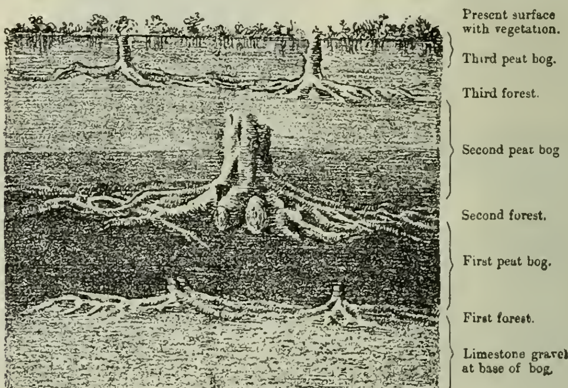

FIG. 141.—Section of an Irish Peat-moss. (From *Knowledge.*)

helps to build up the crust of the earth, and to complete the stages passed through in the formation of coal. If obtained near the surface of the ground, it is an incoherent mass of vegetable fibres. As it is traced lower it becomes more compact, gradually losing its fibrous appearance. It is formed at the bottom of marshes, which occur in a variety of situations, as, for instance, round the margin of a lake. Water-loving plants, like mosses, by their rapid growth, gradually encroach upon the lake, until eventually it may be obliterated, its place being taken by a mass of vegetable matter, still growing on the top, but beneath made of the accumulation of the roots and dead parts of the plants of many previous years. Such areas constitute *peat-mosses* or

bogs. These are very abundant in temperate countries, where the conditions are favourable for their formation. A section of an Irish peat bog, showing the growths of three successive submerged forests, is given in Fig. 141.

Lignite.—If the land on which a peat bog has been formed subsides to any extent, it will probably become covered with water, and there may be deposited above it a bed of sedimentary rock. This will subject the peat to pressure, and cause it to become further compacted. The form then assumed is that of a brown rock, called brown coal, or *lignite.*

Coal.—If such changes as those just mentioned be repeated and continued through a long time, the vegetable nature of the deposit is completely obliterated, and the resulting product is known as *coal.* We can define coal as *mineralised vegetation.* The plants from which coal was formed lived long ages ago, when the variety of vegetable forms was much smaller than it is now. All of them were flowerless, and such plants the botanist calls *cryptogams.* The cryptogams include ferns, mosses, horsetails, club-mosses, &c., all of which are found living to-day, but having little importance compared with the flowering plants, which include forest trees, &c. We should not speak of coal as being formed from forests, or we give the impression that trees, as we know them, grew at the time the plants, which formed the coal, flourished. It is quite true that some of the ferns and other flowerless plants grew to a great size, as large as some of our trees, but size alone does not make a tree. Coal was probably formed from masses of vegetation, like those which constitute the mangrove swamps of tropical countries. It is not common to find complete plant remains in coal itself, but in the shales associated with it perfectly preserved leaves and other parts of plants occur.

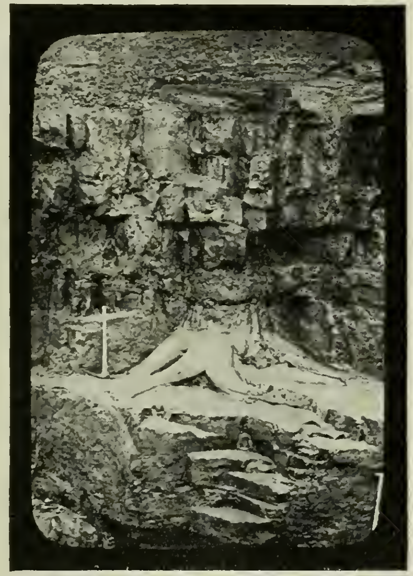

FIG. 142.—A Bed of Coal showing the Trunk of a large Coal Plant. From a Photograph by Mr. A. G. Nichols.

Anthracite is more highly mineralised than ordinary coal. It contains a greater percentage of carbon and a smaller amount of hydrogen in 100 parts than ordinary coal. It is sometimes called smokeless coal, because of the way in which it burns.

Graphite.—If everything but the carbon is got rid of by the action of the pressure and heat which brings about the various changes we have described, the final result is the allotropic variety of carbon known as graphite.

TABLE SHOWING DIFFERENCE IN CHEMICAL COMPOSITION OF CARBONACEOUS ROCKS.

	Composition of 100 parts.		
	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Wood . . .	50	6	44
Peat . . .	60	6	34
Lignite . .	68	5	27
Coal (average)	85	4	11
Anthracite .	94	3	3
Graphite . .	100	—	—

The table reveals the chemical meaning of mineralisation. It is seen, that, as the process is completed, there is a regular diminution in the amount of hydrogen, oxygen, and nitrogen, which are eliminated in the form of such compounds as water and ammonia, and a corresponding increase in the amount of carbon in 100 parts.

METAMORPHIC ROCKS

Meaning of Metamorphism.—We have seen that granite is slowly altered by the action of atmospheric agencies, causing it to eventually become completely disintegrated or broken up. Such a change as this is referred to as *alteration*, as are all those changes brought about by the action of air and water, and are often only enough to modify the rock, which still retains its original structure. Those changes which cause a rock to completely lose its original texture and to become crystalline are classed as *metamorphic changes*, and are said to be due to *metamorphism.* Metamorphism is caused in two ways (1) *by the action of heat* when it is called *contact-metamorphism;* (2) *by the action of pressure exerted from the sides*, *due to movements in the earth's crust*, and called *dynamo-metamorphism.*

In the first of these the heat is generally derived from great masses of igneous rock which have been intruded among sedimentary deposits. In this place we shall only be able to

describe a few of the rocks which have been changed in this way. The student should consult books on Geology for an account of metamorphism.

Metamorphic Rocks formed by the Action of Heat. —*Porcellanite* and *Lydian Stone* are formed by the contact-metamorphism of clays and shales. They are hard, flinty-looking rocks.

Quartzite is formed in the same way from sandstones, which are more or less completely made up of pure quartz-grains. It differs from sandstone in not being divisible into grains by

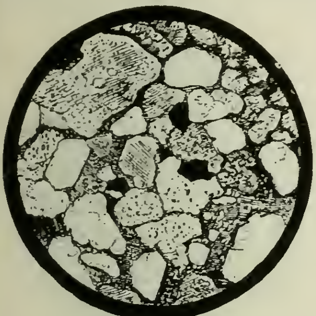

FIG. 143.—A Metamorphosed Sedimentary Rock (after Forbes). The microscopic section shows it to be composed of grains of quartz, &c., which have become firmly compacted together.

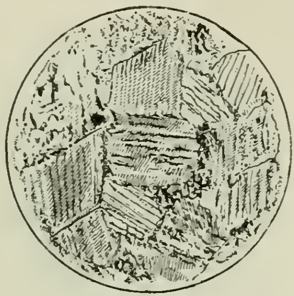

FIG. 144.—Microscopic appearance of Marble.

pounding. The grains have become cemented together and the rock breaks with a conchoidal fracture, almost like bottle-glass (Fig. 143).

Marble is the result of the action of contact-metamorphism upon limestone. It is often traversed by veins of other minerals which give rise to the "marbled" appearance. Its appearance under the microscope is shown in Fig. 144.

Metamorphic Rocks formed by the Action of Pressure.—*Slate* results when shales are subjected to metamorphism of this kind. Originally the shales split only along the lines of bedding, or as it is sometimes expressed, shale is a *laminated* rock. After the action of great lateral pressure the

rock can be *cleaved*,—the lines of *cleavage* being in a new direction,—into thin plates, like roofing-slates. That this property of cleavage is the direct result of an enormous pressure from the sides has been shown experimentally. An examination under the microscope of the shale before the action of this pressure, and of a slate after it has acted, shows the nature of the internal changes which have taken place (Figs. 145 and 146).

Schists exhibit a structure differing both from lamination and cleavage. They are said to be *foliated*. This *foliation* differs from both the structures described under slate. In a foliated rock the layers or folia cannot be easily separated. They are

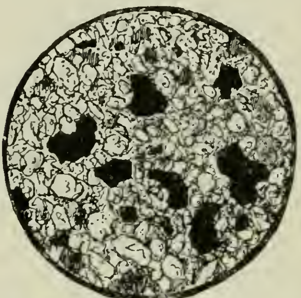

FIG. 145.—Microscopic section of Shale. (Forbes.)

FIG. 146.—Microscopic section of a Slate, showing minute structure of a Cleaved Rock. (Forbes.)

not strictly parallel to one another, but form lenticular-shaped patches, that is, layers which are thickest in the middle and thin away towards both ends. The minerals of which they are composed have been aggregated into thin layers which are welded together to a considerable degree, as well as often being much contorted and crumpled. The following are some of the commonest schists :—

Hornblende-schist is a schistose mass of common hornblende interleaved with felspar, quartz, or mica.

Mica-schist consists of a similar rock made up of folia of mica and quartz, the relative proportion of the two minerals varying considerably in different specimens.

Argillaceous-schist, or clay slate, has a very variable composition. It is the result of dynamo-metamorphism on a variety of argillaceous deposits. The class includes many rocks to which special names have been given, such as *whet-stone*, *hone-stone*, &c.

Gneiss is composed of the same minerals as granite, which are arranged in folia very much thicker and coarser than those making up rocks like mica-schists. Many varieties are known, depending upon the accessory minerals and the nature of the folia. The folia are often recognisable even in small specimens.

Chief Points of Chapter XIX.

Igneous Rocks by their disintegration give rise to

INSOLUBLE SILICA in form of Quartz grains which is carried away in suspension by running water and deposited to form SILICEOUS AQUEOUS ROCKS which include *Sandstones*, *Grits*, *Conglomerates*, *Breccias*.	INSOLUBLE ALUMINIUM SILICATE which is carried away by running water and deposited to form ARGILLACEOUS AQUEOUS ROCKS which include *Clays*, *Mud and Silt*, *Mudstone*, *Shales*.	DISSOLVED SILICA extracted from water (*a*) By Plants (*Diatoms*) to form *Diatomaceous Earth*, (*b*) By Animals (*Radiolaria* and *Sponges*) to form *Radiolarian Earth*, *Sponge spicules*, (*c*) By chemical means to form *Siliceous Sinter*.	DISSOLVED CALCIUM CARBONATE extracted from water (*a*) By Plants (*Algæ*) to form *Coccospheres*, (*b*) By Animals *Foraminifera*, *Polyzoa*, *Calcareous Sponges*, *Corals*, *Echinoderms*, *Molluscs*, etc. to form *Chalk*, *Limestones*, (*c*) By chemical means, to form *Travertine*, *Stalactites*, *Stalagmites*, *Oolites*.

Carbonaceous Rocks.

Peat Carbon 60 per cent. sp. gr. ·55.	Lignite Carbon 68 per cent. sp. gr. 1·04.	Coal Carbon 85 per cent. sp. gr. 1·40.	Anthracite Carbon 94 per cent. sp. gr. 1·50.

Metamorphic Rocks.

Formed by action of Heat (*contact-metamorphism*)	Formed by action of Lateral Pressure (*dynamo-metamorphism*)
Porcellanite and Lydian-stone	CLEAVAGE ROCKS
Quartzite	*Slate*
Marble	FOLIATED ROCKS
	Hornblende-schist,
	Mica-schist,
	Argillaceous schist
	Gneiss.

A Selection of Aqueous Rocks.—Sandstone, micaceous flagstone, clay, shale, chalk, oolitic limestone, crystalline limestone, dolomite, coal.

QUESTIONS ON CHAPTER XIX.

(1) Explain the formation of stalactites and stalagmites.

(2) Describe two rocks formed by the aid of animals or plants.

(3) Compare the composition of wood, lignite, and anthracite as regards carbon, hydrogen, oxygen, and nitrogen.

(4) What is meant by metamorphism as applied to rocks, and how is it caused?

(5) State what you know of the appearances of pieces of sandstone, volcanic scoriæ, peat, obsidian, shale, and gneiss.

(6) Classify the following into minerals, aqueous rocks, and igneous rocks: dolomite, coal, basalt, calcite, chalk, diorite, augite, opal, and rhyolite.

(7) Classify the following rocks into aqueous, igneous, and metamorphic: chalk, flagstone, basalt, gabbro, crystalline limestone, mica-schist, clay, gneiss, and granite.

CHAPTER XX

INTERNAL FORCES ACTING ON THE EARTH'S CRUST

Final Result of the Action of External Forces.—Attention has been called, from time to time, to a series of agencies, acting from outside the earth, which conspire together to wear away that part of the crust which is above the sea-level. It has been shown that wind, rain, frost, running water, and the sea are all of them, each in its own measure, wearing away and breaking down the solid rocks building up the land-masses, which constitute a habitation for the animals and plants which people the earth's surface. Were there no agencies at work to compensate these *external forces*, it is clear the final result would be that eventually all the continents would be worn down to the sea-level, and the detritus and other materials resulting from this universal denudation would be deposited at the bottom of the ocean, which, gradually spreading, would cover the globe. Such a contingency does not arise because compensating agencies do exist, and it is to these *internal forces* which we have to direct attention in this chapter.

Nature of the Internal Forces.—These agencies which act from inside the earth can best be considered under three classes, viz., (1) Volcanoes and volcanic action. (2) Earthquakes. (3) Slow movements of elevation and depression. They can one and all be traced to the internal heat of the earth, which, as has been seen, is to be regarded as the relic of an original molten condition of our planet. That the interior of the earth is at a much higher temperature than the crust is concluded from observations like the following :—

(*a*) The materials ejected from volcanoes are at a very high temperature. Those substances which are liquid at ordinary temperatures, such

as water, are emitted in a gaseous condition. Those which are solid at the temperature of the earth's surface, like lavas, are ejected in a liquid state. The inference is that the locality from which they are derived is at that temperature which is necessary to bring about these results.

(*b*) The temperature rises as the centre of the earth is approached. The rate of increase met with in deep mines and borings varies in different places for a variety of reasons, such as the different specific heat and conducting power of the rocks. An average result according to the British Association Committee is an increase of 1° F. for a descent of 64 feet.

(*c*) The temperature of the waters of artesian wells, hot springs, and geysers, is higher than that of surface waters. The temperature of the water of the hot springs at Bath is 120° F., that of some of the geysers of Iceland, 190° F.

Volcanoes and Volcanic Action.

Definition of a Volcano.—A volcano is nothing more than a hole, usually a crack, connecting the exterior and the interior of the earth. The definitions still given in some geography books that it is "a burning mountain" is altogether wrong. Of *burning*, as the student has learnt to regard it in a previous chapter, there is none. Nor need a volcano be a mountain. Although the accumulation of the ejected materials round the hole in the crust often causes a hill to be built up, there is sometimes no such mound formed, indeed in some cases there is an actual depression. The definition becomes more complete if we add that from the hole in the crust are ejected, sometimes with explosive violence, various materials, which are generally at a high temperature. Our definition thus becomes :—*A volcano is a hole, usually a crack, connecting the exterior and interior of the earth; from it are ejected, often with explosive violence, various materials, which are generally at a high temperature.*

Kinds of Volcanoes.—Volcanoes may be divided into classes depending upon the frequency of the eruptions which take place. *Active* volcanoes are those from which an eruption can be expected at any time. If there is no cessation of activity of some degree, we have a *constant* volcano, like Stromboli. If the eruption is more or less regularly followed by a period of rest, such a volcano is called *periodic*, like Vesuvius. If the

period of rest extends into a great number of years, and is then followed by an eruption, it is spoken of as *dormant*; and in those cases where the activity seems to have ceased altogether, we have *extinct* volcanoes.

Materials ejected from Volcanoes can be classed under three heads, according to the physical condition in which they are emitted, viz., *gaseous*, *liquid*, *solid*.

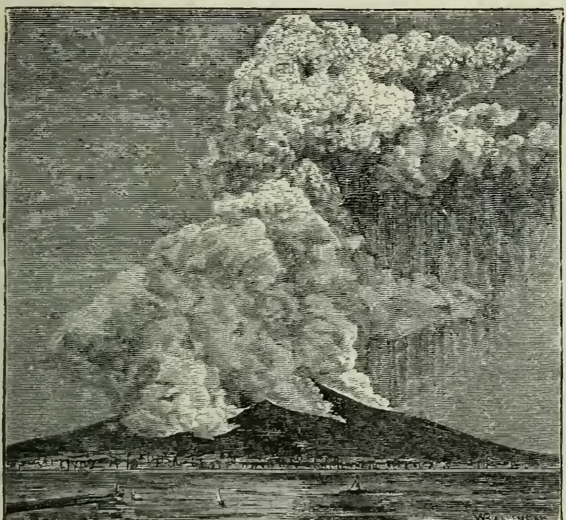

FIG. 147.—A Volcanic Eruption.
[That of Vesuvius on April 26, 1872.]

The chief *gas* given off from a volcano is *steam*. This vapour is evolved in enormous quantities. The air round the volcano becomes so saturated with moisture that the steam accumulates as clouds of great extent, and is condensed into torrents of rain, as seen in Fig. 147.

In addition to steam, we also have emitted *carbon dioxide*, *sulphur dioxide*, *hydrochloric acid gas*, with others, though in very small quantities only.

The *liquid* material which is given off by a volcano is known as *lava*. Its degree of fluidity depends upon its chemical composition.

The lavas which when cooled form acid igneous rocks (p. 291) are least fluid, the basic lavas are most fluid. The bottom of a lava stream cools most quickly and forms a glassy rock like obsidian. The top of the stream, in contact with the air, cools more slowly, forming a rock which looks like a clinker. It gives off steam in cooling, and this gas in escaping causes the lava to be filled with holes and gives rise to a *vesicular* rock. *Pumice* is formed by the expansive force of steam upon

FIG. 148.—Part of a Lava-stream on Vesuvius. (Abich.)

acid lavas. From the cindery appearance which some cooled lava-streams have, the term *scoriaceous* has been derived, and is often used to describe the volcanic rocks so formed. Lavas, the basic kinds especially, sometimes take a beautiful columnar form on cooling, like the basalt columns of the Giants' Causeway and Fingal's Cave. This columnar structure is shown in Fig. 149.

The *solid* materials ejected from volcanoes are usually of a fragmental kind. They include bombs, lapilli, and dust. *Bombs* are lumps of lava forced off the ascending liquid column by the current of issuing

steam. They are whirled round and round in the air, and get a roughly spherical form. They cool rapidly on the outside into a glassy shell, but inside are much more crystalline. *Lapilli* are angular fragments of lava similarly forced off by the issuing steam. The larger pieces are known as *scoriæ*, the term lapilli being reserved for pieces varying from the size of a pea to that of a marble.

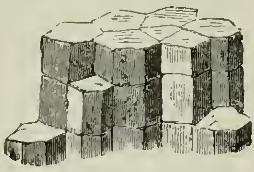

Fig. 149.—Ordinary Columnar Structure of Lava.

Cause of Volcanic Action.—From the bottom of the sea and lakes, from the surface of the land everywhere, water is continually passing into the crust of the earth. This goes on through every crevice. Sometimes by its own weight, and often, when the cracks are only minute, by capillary attraction, an enormous amount of water must reach the interior. But as we descend the temperature increases, and by and by reaches a point at which the water is wholly converted into steam. This temperature will be much higher than the boiling-point of water at the sea-level, because the pressure to which the water is subjected in the earth's interior is very great. Steam will be formed continuously, and thus there will be more and more vapour compressed into a given space, which, the student knows (p. 202), will cause the pressure of the steam to become greater and greater. Just as in a boiler the pressure of the enclosed steam can only be safely increased up to a certain point, beyond which a further addition to the pressure will cause the material of the boiler to break, resulting in an explosion, so the pressure of the steam enclosed within the earth's crust can only go on without an explosion so long as the pressure of the steam upwards is less than that of the weight of the rocks downwards. When the pressure of the steam is increased beyond this point, a volcanic eruption takes place. Either a new crack is formed in the earth's crust through which the materials we have described are ejected, or the solidified lava in an old volcanic vent is violently forced out and a new eruption takes place from an old volcano.

A Volcanic Eruption.—The order of events throughout a volcanic eruption is by no means uniform, but there are many phenomena which generally occur. In the eruption as we shall describe it, no particular instance is referred to, but the chief events are narrated in the order in

which they would probably happen. When the neighbourhood has been quiescent for some time, the advent of a new disturbance is generally heralded by loud rumbling noises from the earth's interior, which are often followed by earthquake shocks (p. 322). There may be at this time, too, a fairly universal interference with the direction and nature of the streams, as well as of the sea-level in the neighbourhood. These premonitory signs last for varying periods. They are followed by an increase in the amount of steam which escapes from volcanic vents in the district as well as by a raising of the level of the lava in the throat of such vents. Then a mighty explosion takes place. There is a sudden and violent escape of a huge volume of pent-up steam. The force with which it issues is so tremendous that it scatters lumps, which it tears from the sides of the throat, in every direction, propelling some of them, often of enormous sizes, far up into the air. Cases are on record where the expansive force of the issuing steam has been so great that the cone accumulated during previous eruptions has been blown into minute fragments. The particles formed in this way constitute the volcanic dust which is given off in great quantities. The clouds of steam often take the appearance of huge flames and are accountable for the popular ideas of a volcano. The molten lava which now fills the neck of the volcano is at so high a temperature that it is luminous. The light it emits is reflected from the banks of steam above and they themselves are transfigured, appearing to be a blaze of light. The water vapour with which the atmosphere is saturated becomes condensed and falls as torrents of rain. The falling rain brings down with it much of the volcanic dust and together these result in the formation of streams of volcanic mud which flow down the sides of the cone. The mutual friction of the particles of vapours and dust cause the overhanging clouds to become electrically charged, and eventually result in the thunder and lightning which add to the weirdness of the scene. The showers of scoriæ, lapilli, and dust cause a continual addition to the size of the cone. The dust, too, in the presence of winds, becomes carried huge distances, sometimes many thousands of miles. A notorious example was afforded by the eruption of Krakatoa, when the dust was carried from the Malay Archipelago as far as our country, its influence here being felt in the gorgeous sunrises and sunsets to which it gave rise. Finally, we must mention the streams of lava which begin to flow when the liquid rocks from the interior well over the sides of the crater's mouth. These rivers of molten rock are sometimes of gigantic proportions, being known of so great a volume that villages have been buried under them as they advanced with irresistible force.

Different kinds of Cones.—We shall describe cones under four heads, viz. : (1) *Scoriæ* or *Cinder* cones. (2) *Tuff* cones. (3) *Lava* cones. (4) *Compound* cones.

The plan on which they are all constructed follows the same lines, and it will be desirable to first briefly refer to the *structure of a cone*. The materials from which the cone is built up are

thrown out from a crack in the crust, which we must regard as the starting point. These fragments severally describe curves, after the pattern of those of the drops of water from a fountain. In this way a circular deposit of ejected material is formed round the orifice as a centre. As the eruption continues this heap of fragments increases in height, and the mound slopes towards and from the hole at an angle depending upon the nature of the materials. This angle is called the "angle of rest." Eventually the inner slopes close in towards one another, and from the outside we appear to have a simple conical hill. If, however, by any means the internal structure becomes revealed, it will be seen that on every side of the orifice there is a hill, the sides of which respectively slope towards and away from the vent (Fig. 150).

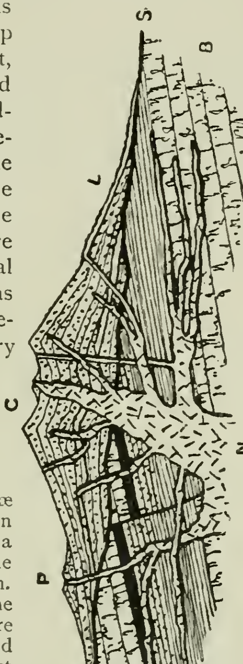

Fig. 150.—Section of a Volcanic Cone. B, beds through which eruption has broken; C, crater; L, a lava-flow; N, main volcanic neck; P, a parasitic cone; S, old land surface. From *Open Air Studies*, by Prof. G. A. J. Cole. (Chas. Griffin and Co., Ltd.)

Cinder Cones are made of scoriæ or lapilli. These are usually dark in colour, which becomes changed to a reddish hue by the action of the rain upon the magnetite they contain. Though, from the loose nature of the materials of which such cones are built, it might be expected they would easily be washed away by the rain, yet as the extinct cinder cones of Auvergne show, such is not the case. There cones do in time become covered with a soil, but this does not destroy their form. The angle of slope of this ordes of cone is from 35°–40°, this being the "angle of rest" of such material as scoriæ. These cones are generally higher on one side, which side indicates the direction in which the wind was blowing at the time of the eruption. One kind of scoriæ cone is made of *Pumice*, as that of Campo Bianco, in the island of Lipari.

Tuff Cones.—Tuff is the solidified volcanic mud to which reference has been made. The angle of slope of these cones is much smaller

than in the previous kind. It varies from 15°–30°. Their internal character is the same as that of cinder cones. Their colour is much lighter because of the more acid nature of their composition. These cones eventually become water-tight. The crevices become filled with the kaolin which results from the decomposition of the felspars contained in the tuffs. If such a cone becomes filled with water we have a lake formed like some in the north of Italy.

Lava Cones.—The form of these depends upon the degree of liquidity of the lava from which they are formed. Viscid lavas form steep cones. Very fluid lavas give rise to cones with a gentle slope. The gradual inclination of the sides of the lava cones at Hawaii is due to the great liquidity of the basic lavas there found.

Compound Cones are those partaking of the characters of all or some of those already described. They are partly built of scoriæ, partly of tuffs, and in some parts of lava. The larger number of cones are of this compound nature. The variable materials of which the cone is built cause it to assume beautifully curved forms as the "angle of rest" of one material gives place to that of another. After a cone has reached a certain height it often happens that the force of the enclosed steam, to which eruptions are due, is insufficient to force the lava high enough for it to flow over the neck of the cone. In such cases the molten rock is forced through an opening which gets made in the side of the cone. Often round such secondary necks new smaller cones are formed which constitute *parasitical cones* (Fig. 150).

Distribution of Volcanoes.—Volcanoes generally occur arranged in lines. This *linear arrangement* is very marked along the coasts round the Pacific Ocean. Many important active volcanoes, however, are found upon islands. The connection between this nearness to the sea and the cause of volcanic action will be at once apparent from what has gone before. The line which is followed by the volcanic activity on the earth can be traced, beginning from the most southerly limit of the American continent, up the western coast of South America following the line of the Andes. through Central America along the west coast of the northern half of the great continent, by way of the Rocky Mountains, into the Aleutian Islands. Thence it passes by way of the Kurile Islands and Japan, all down the western sea-board of Asia, as far as the Malay Archipelago. Here the line divides, one branch passes in a north-westerly direction to Java and Sumatra; the other turns south-eastwards through New Guinea and passes on to New Zealand.

The line of volcanic activity is not so marked in the Atlantic Ocean. It can be traced from Jan Mayen, through several islands, Iceland, Azores, Ascension, St. Helena, to the West Indies. Nearer home there is a well-marked line in the Mediterranean along which Stromboli, Vesuvius, and Etna occur.

Other forms of Volcanic Activity.

—These can be traced to the same general causes as those which result in volcanoes. They include *geysers*, *mud volcanoes*, and *solfataras*.

Geysers.—The name is derived from an Icelandic word,

meaning a "roarer." They consist of fountains of hot water, which are intermittently active. Huge quantities of hot water and steam are suddenly forced up to a great height, and the eruption is followed by a period of rest. They differ from volcanoes only in the absence of fragments and molten rock. Their mode of formation is well shown by an ingenious model designed by Bunsen. A column of water is heated in one part by a fire suitably situated. This gives rise to the development of a quantity of steam, which by its expansive force, at the moment the pressure becomes high enough, forces all the water above it up into the air to a height depending upon the extent of such pressure. The water of geysers is often nearly saturated with silica and other compounds, which commonly become deposited round the mouth of the geyser, forming *sinter* in the case of the silica. Geysers are common in Iceland, the Yellowstone Park of the United States, New Zealand, and other places.

Mud Volcanoes, or *salses*, are formed in those cases where the geyser is active through beds of a clayey nature. When this is the case, instead of comparatively clear water being erupted, we have *mud* given off, from which small cones are formed. They are known in Iceland, Java, &c.

Solfataras.—If only steam and other gases are evolved from a vent in a region of volcanic activity we have what is called a *fumarole*, and if sulphur vapours are largely present among such gases it is known as a *solfatara*.

Earthquakes.

Their Nature.—From what the student has read about waves in Chapter VII., he will be able to understand what is meant by saying that *earthquakes are waves of compression in the earth's crust*. The particles of the crust, like those of the air in the propagation of a sound wave, have, in turn, a to and fro movement. The original impulse is the result of a disturbance at some distance beneath the earth's crust, the nature of which is not properly made out. It may be due to the expansive force of steam under pressure, or to the movements of masses of rock such as those which cause geological *faults*, or to some other cause. Whatever its nature, this original impulse causes the particles in its neighbourhood to be violently displaced, and by

virtue of the elasticity of the rock this displacement is transferred from one particle to the next all along the direction of propagation of the wave. These movements are going on continually. The slight ones, which are all that happen regularly, are called *earth tremors.* These are brought about by every slight disturbance of the crust, such as are caused by diurnal variations of temperature.

Earthquakes are violent tremors.—The wave is propagated outwards from the place of disturbance, called the *seismic centre* in every direction ; or, the waves are spherical. When the wave reaches the surface of the earth, it is felt as an up and down movement, and anything which is of an unstable nature is unable to resist this motion and falls. This is particularly the case with chimneys, steeples, obelisks, and so on. For this reason the houses in Japan—where earthquake shocks are very common—are constructed of light and pliable materials like bamboo and paper, which are able to stand the movements without fracture. Darwin remarked, when in South America, that it was a common thing for this up and down movement of the crust to cause the trees to dip, and recover themselves, as the wave passed under them.

Earthquake Shocks give rise to Three Kinds of Waves.—These are:—(1) Earth-waves ; (2) Water-waves : (3) Air-waves.

The *earth-wave* is that which travels through the land. Some of its effects we have already noted. It is the most destructive kind of wave and must be regarded as the most striking feature of an earthquake. It sometimes results in an opening and closing of the earth, which is, however, a secondary effect.

Water-waves. When the primary shock happens below or near the sea, after the earth-wave has traversed the intervening land, it is transferred to the water and gives rise to a great wave in the ocean. Ships happening to be in deep water are only subjected to an up and down movement. As the wave approaches shallow water it becomes fearfully destructive. Breaking, it changes the character of its motion. The water as a whole is carried forward, and rushes on to the land with terrific violence, causing, as at Lisbon, the most awful damage and loss of life.

Air-waves also are produced. When the length of the wave is such as to bring it within the range of hearing, it is recognised as a sound-wave. Such sounds can be heard for enormous distances. Very often, however, the wave-length is so great that the ear is unable to detect the presence of the disturbance, but these long waves can be recognised in other ways.

Observation of Earthquake Shocks.—To properly estimate an earthquake-wave it is necessary to know several things about it, viz., (1) Its direction; (2) its intensity; (3) its velocity. To ascertain these it must be borne in mind that an earthquake results from a series of

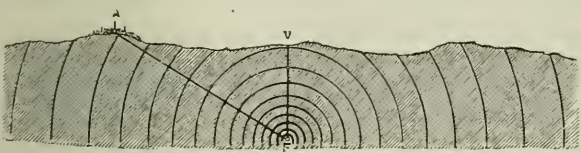

FIG. 151.—The Nature of Earthquake Waves.

spherical waves like that shown in Fig. 151. This diagram shows a section of the crust through which the waves are passing. F is the seismic centre, or the locality from which the shock originates. The shortest line between this spot and the surface is called the *seismic vertical*, FV. If we know the distance between V and the house A, and also the size of the angle VFA, it is easily possible to calculate the

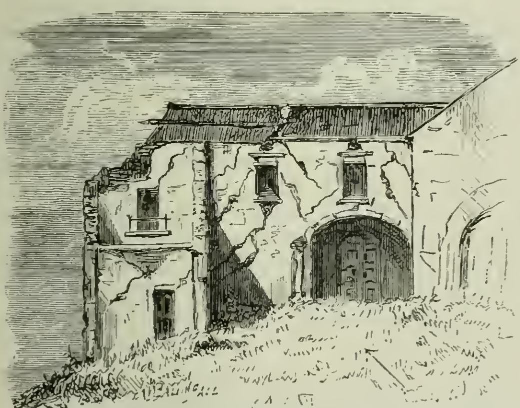

FIG. 152.—Wall shattered by an Earthquake. The path of emergence is in the direction of the arrow. (After Mallet.)

length of the vertical VF or the distance of the disturbance beneath the surface. Mr. Mallet has found that this depth is sometimes not much greater than five miles, though observers before him calculated the distance to be sometimes as great as forty miles. The size of the angle VFA can be found by noticing the direction of the cracks formed in the

walls of houses as at A by the passage of the earthquake shock, as in Fig. 152, where the arrow shows the direction in which the earthquake-wave must have emerged. Mallet also found the average velocity of earth-waves to be about 789 feet per second, though the value varies from place to place, depending, amongst other conditions, upon the elasticity of the rocks in any place.

Seismological Instruments.—The study of earthquakes constitutes *seismology*, and the instruments used in pursuing this branch of knowledge are called seismological instruments. These are of two kinds; (1) *seismoscopes*, which determine the occurrence of earth-tremors, and can be of a very simple nature, such as a bowl of mercury the surface of which is caused to ripple by the minutest movement of the earth's crust. Measurements of the amount of the disturbance of the mercury can be made by floating in it a piece of iron to which a mirror is attached. A reflected ray of light is moved along a suitable scale by the up and down movement which the float experiences. Seismoscopes which can be used to measure the amount and direction of an earthquake shock are called *seismometers*. A simple form of seismometer consists of two rows of wooden blocks, of equal base, but varying heights, arranged at right angles to one another. The higher blocks topple over on the occasion of quite slight earthquakes, and the more intense the shock the shorter the block which falls over. The direction in which the blocks fall gives the direction in which the wave is travelling. The most common seismometers are, however, delicately-suspended pendulums—sometimes these are capable of keeping a record of their own movements and are then known as *seismographs*.

Slow Movements of Elevation and Depression.—These movements are small in amount and extend over long periods of time. They are for this reason referred to as *secular* movements. The earth is popularly quoted as an almost perfect example of stability, while the ocean is looked upon as ever changing its level. We have now to see that in reality the reverse of this is true. The sea-level (p. 249) is really constant and from it the height of places on the land is reckoned. The land-level is continually changing, being raised in some districts and depressed in others.

Proofs that the Level of the Land is being raised in some Parts of the earth are of several kinds:—

(1) *By the beds of sea-shells, similar to those of animals still living in the sea, found near the coasts of various countries, raised to different heights above the sea-level.* Along the coast of South America such shells are found at a height of 1,300 feet; in Norway up to 700 feet; and along the shores of Sweden at elevations varying from 100 to 200 feet.

(2) *By the raised beaches which occur round the coasts of Britain and*

other countries. These old sea-terraces were evidently at one time at the margin of the sea. This is placed beyond a doubt by the water-worn rocks constituting the old sea-caves which often form the background of such beaches. *Raisea beaches* of this kind occur at various places round the Scottish coast and in one or two places round England. They are very well shown in the north of Norway, where a whole series occurs up to a height of more than 600 feet.

(3) *By the present elevated position of certain human erections which were originally at the sea-level.* A good example is afforded by the old Greek docks, which are now found much above the sea-level on the southern coast of Crete. Many other cases are known which we have no space to describe.

Proofs that the Level of the Land in some parts is Sinking.—

(1) *By the present position of certain human erections below the water, which were originally built above the sea-level.* This is true of several old streets of some sea-ports on the south coast of Sweden. The poles which the fishermen of Greenland in past times have put into the beach as an attachment for their boats now lie useless below several feet of water. Similarly, new posts are being continually put in to take the place of those which become submerged as the land sinks.

(2) *By the submerged forests which are not uncommon round the coasts of Devon, Cornwall, and other places.* From the nature of the trees which make up these forests we are quite sure that they must have once thrived on the land. Their present position gives an unmistakable proof that the land is sinking in these parts, or, at all events, has sunk in past times.

(3) *By the existence of coral at a depth of as much as* 1,800 *feet in certain coral-reefs, though it is well-known that the coral polyp, which builds the coral, cannot live below a depth of about* 120 *feet.* If Darwin's observations on coral reefs are considered as conclusive, their structure affords undoubted proof of the subsidence of the land in the districts where they occur. The small coral animal, or polyp, must have commenced its work at a depth of about 120 feet, and have built upwards at something like the same rate as the land was sinking. At first the coral would form a ring round the island, such as is seen in section in Fig. 153.

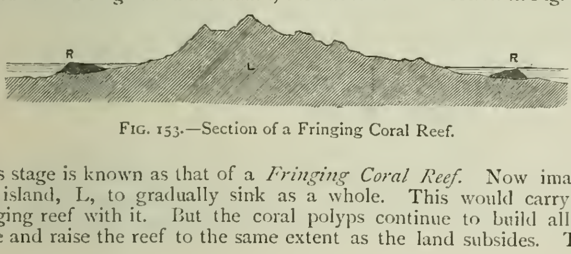

FIG. 153.—Section of a Fringing Coral Reef.

This stage is known as that of a *Fringing Coral Reef.* Now imagine the island, L, to gradually sink as a whole. This would carry the fringing reef with it. But the coral polyps continue to build all the time and raise the reef to the same extent as the land subsides. They

also build more quickly on the outside, where the supply of food is best maintained, and as a result the fringing reef gradually assumes the *Barrier Reef* stage (Fig. 154), where a small island is surrounded by a

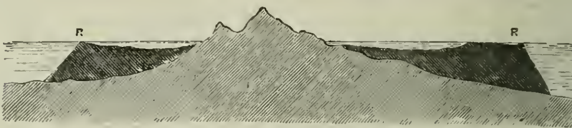

FIG. 154.—Section of Barrier Reef.

circular coral reef. The continuance of the same process eventually carries the island, L, completely beneath the water and all that is seen at the surface is a circular island of coral, known as an *atoll*, as in Fig. 155. This explanation of coral reefs is not universally accepted. Dr. Murray has found that in the neighbourhood of some of these islands

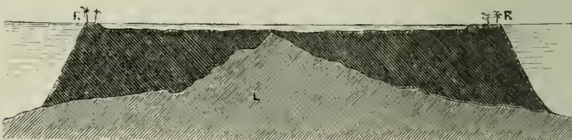

FIG. 155.—Section of an Atoll.

the land is actually rising, and has proposed another theory of their formation. There can be little doubt, however, that Darwin's theory is a correct explanation of the way in which some coral reefs are built.

CHIEF POINTS OF CHAPTER XX.

Results of Action of Internal Forces.—(1) Volcanoes; (2) earthquakes; (3) slow movements of elevation and depression.

Indications of High Internal Temperature.—(1) Volcanic products are at a high temperature; (2) the temperature increases in descending below the earth's surface; (3) geysers and certain springs eject hot water.

USUAL VOLCANIC PRODUCTS.
- *Gaseous*, steam, carbon dioxide, hydrochloric acid gas, sulphur dioxide, &c.
- *Liquid*, lavas
- *Solid*, scoriæ, lapilli, volcanic bombs, and dust.

Phenomena of Volcanic Eruptions.—(1) Violent explosions; cause, by ejection of steam and gases; (2) bright glow seen above volcano at night: cause, reflection from glowing lava upon steam-cloud above; (3) darkness during day: cause, formation of clouds and

masses of volcanic dust; (4) thunder and lightning: cause, the electricity produced by friction of escaping particles against vent and against one another; (5) earthquake shocks and rumbling noises: cause, explosions of steam and disruption of rocks below earth's surface; (6) copious rain charged with dust: cause, condensation of mixture of steam and volcanic dust; (7) streams of lava issuing from vent and through cracks on sides of volcano.

Materials Ejected during various Volcanic Actions.—(1) Ordinary volcanoes: steam, lavas, fragmentary products; (2) geysers: hot water containing substances in solution; (3) Fumaroles: steam, carbon dioxide, and other gases; (4) Solfataras: steam, carbon dioxide, and a large proportion of sulphur vapour; (5) mud-volcanoes: a mixture of finely-divided particles, water, and gases.

Varieties of Volcanic Cones.—(1) Cinder cones, made of scoriæ or lapilli; (2) tuff cones, made of solidified volcanic mud; (3) lava cones, produced by the solidification of liquid rock; (4) compound cones, composed of scoria, tuff, and solidified lava; (5) parasitic cones, formed on the sides of the main cone.

Earthquakes are waves of compression in the earth's crust caused by—(1) the expansive force of steam under pressure; (2) the dislocation of rock-masses beneath the surface.

Earth Tremors are slight shakings continually taking place in the earth's crust; they can be classified into—(1) irregular tremors, due to internal action and faulting; and (2) regular tremors produced by the daily warming and cooling of the earth's crust by the sun.

The Results of Investigations of earthquakes show—(1) that the depth of the disturbance is rarely greater than ten miles; (2) that the shocks are transmitted by (*a*) earth-waves, (*b*) water-waves, (*c*) air-waves; (3) that the velocity of earth-waves varies from about 800 feet per second to about two miles per second—the velocity of water-waves is less than this.

Indications of Slow Movements.

Of Elevation.	Of Depression.
(1) Beds of the shells of marine animals, found above sea-level.	(1) Existence of coral below depths at which coral polyp can live.
(2) Sea-beaches and sea-worn caves above high-tide mark.	(2) Submerged forests.
(3) Elevated position of erections originally at sea-level.	(3) Submerged buildings originally erected at sea-level

Questions on Chapter XX.

(1) Describe and illustrate by drawings as far as possible:—
- (*a*) A volcanic (scoria) cone and its internal structure.
- (*b*) A volcanic crater, stating how it is formed.
- (*c*) A lava stream.
- (*d*) A volcanic *dyke*. (1896.)

(2) State the cause of—
  (*a*) The violent explosions that occur during a volcanic eruption.
  (*b*) The darkness that often exists during the day when an eruption is taking place.
  (*c*) The bright glow that is seen above a volcano at night.
  (*d*) The lightnings that accompany volcanic outbursts. (1895.)

(3) State the composition of the materials ejected from—
  (*a*) Fumaroles.
  (*b*) Geysers.
  (*c*) Mud volcanoes.
  (*d*) Ordinary volcanoes. (1894.)

(4) Point out the errors in the following statements :—
  (*a*) "Earthquakes have raised to heaven the ocean-bed."
  (*b*) "Volcanoes are burning mountains that vomit fire and smoke."
  (*c*) "Coral insects are industrious creatures that cleverly build up islands."
  (*d*) Coal is a mass of leaves pressed together in the earth. (1893.)

(5) State the origin of the following appearances about an active volcano :—
  (*a*) The clouds which collect above it.
  (*b*) The glow seen above it at night.
  (*c*) The flashes of lightning playing about the cloud
  (*d*) The sounds which are heard. (1892.)

(6) What is meant by a "raised beach"? What do we learn from its existence? Name any place where raised beaches are found. (1891.)

(7) How has it been found out that the deeper parts of the earth's crust are hotter than those near the surface? (1890.)

(8) State the grounds on which it is inferred that volcanic eruptions take place through fissures in the earth's crust. (1889.)

CHAPTER XXI

TERRESTRIAL MAGNETISM

WE have still to regard the earth with reference to another of its many characters. *The earth is a magnet*, and in this final chapter the endeavour is made to show what is involved in this statement. This can best be done by studying those properties of certain kinds of matter which are called *magnetic*, the bodies which possess them being known as *magnetic bodies*. We shall first describe naturally magnetic substances and proceed to discover how these properties can be transferred to other bodies.

Lodestone.—It has been already pointed out that lodestone is a binary compound of iron and oxygen (p. 136) which occurs in the earth's crust. It is more commonly known as *magnetite* (p. 137). The name lodestone is reserved for those varieties which have magnetic properties; the name itself means "leading-stone" and refers to its early use for navigating ships. This mineral is found in considerable quantities in Scandinavia, Asia Minor, United States, and other places. Its appearance has been already referred to.

EXPT. 206.—Plunge a piece of lodestone into iron-filings. On withdrawing it notice that the filings cling to it. In some places tufts of filings occur showing that in these places the magnetic power is greatest.

EXPT. 207.—Carefully shape a piece of lodestone so that the spots, where the tufts of filings collected in the last experiment, are at the ends of a bar. Support the bar of lodestone in a stirrup and let it hang freely. Notice that, however the lodestone be made to swing, *it always comes to rest in the same line, with one end pointing in the same direction.*

How to Make Artificial Magnets.—EXPT. 208.—Straighten a piece of clock-spring, and rub it from end to end with the same part of the piece of lodestone. Always rub in the same direction. Do this about ten times. Notice that the piece of clock-spring now has the power of picking up iron-filings. It has been *made* into a magnet. We call it an *artificial magnet.*

EXPT. 209.—Procure a *bar-magnet*. This is an artificial magnet made in another way, but depending upon the same principle. Rub an ordinary sewing needle with one end of the bar-magnet. Notice that the needle is now able to pick up iron-filings.

§ EXPT. 210.—Suspend any of these artificial magnets in a stirrup, in the same way as the piece of lodestone in Expt. 207. Observe that they all arrange themselves as the lodestone did, viz., in the same line with one end in the same direction ; and this however they may be made to swing

These experiments teach several important facts. Lodestone is naturally able to attract iron-filings. It naturally arranges itself in a particular way when allowed to hang freely. It can impart these properties to pieces of steel, converting them into artificial magnets. These, in their turn, can make other pieces of steel into artificial magnets. All artificial magnets arrange themselves in the same way when freely suspended.

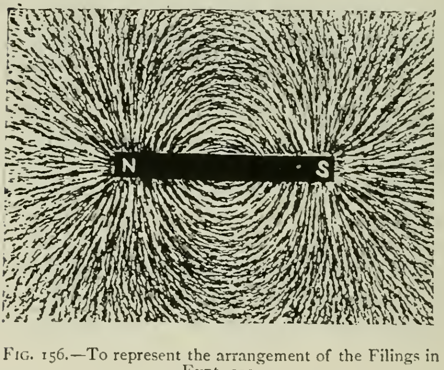

FIG. 156.—To represent the arrangement of the Filings in Expt. 211.

Artificial Magnets.—§EXPT. 211.—Place a sheet of glass over a bar-magnet on a table. Sprinkle fine iron-filings over the glass. Gently tap the glass and notice that the filings arrange themselves as in Fig. 156.

The filings chiefly collect round the ends, which contain the *poles* of the magnet. The poles are places near the ends of the bar-magnet, where the magnetic power is most strongly shown. A line joining the poles is called the *magnetic axis.* A line at

right angles to the axis and midway between the poles is known as the *neutral line* or *magnetic equator.* In the last experiment it will be seen that there are no filings along this line, which appears to have no magnetic properties.

Laws of Attraction and Repulsion by Magnets.

EXPT. 212.—Procure an ordinary compass needle, which is simply a light magnetic needle suspended as in Fig. 157. It can move easily in a horizontal plane. Notice that one end, which is marked, always points towards the north, and is called the *north-seeking* end. Bring up towards this marked end of the compass needle that end of a bar-magnet which points to the north, when it is freely suspended in a stirrup, and which is marked with an N. Notice that they *repel* one another. Repeat the experiment using the unmarked, or *south-seeking*, end of the needle and bar-magnet. Observe they similarly *repel* one another.

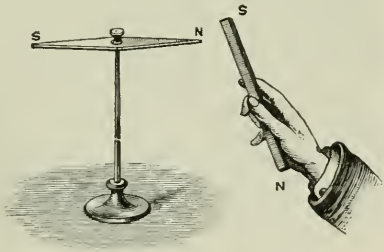

FIG. 157.—Magnetic Attraction.

EXPT. 213.—Repeat the last experiment, only make the unmarked end of the bar magnet approach the marked end of the needle. Observe that they rush together or *attract* one another. Similarly, notice that unlike poles under all circumstances attract one another (Fig. 157.)

These experiments teach the rule referred to as the *First Law of Magnetic Attraction and Repulsion*, which can be stated thus :—

Like magnetic poles repel one another.

Unlike magnetic poles attract one another.

It must, however, be noticed here that, although repulsion is sufficient proof that two like poles are acting upon one another, attraction is not necessarily due to the mutual action of two unlike poles, since as has been seen in Expt. 208, magnets can attract unmagnetised iron which has no poles at all.

Why a Magnetic Needle points to the North.—

EXPT. 214.—Place a bar-magnet upon the table. Arrange a compass needle upon it so that its point of suspension is on the neutral line of the magnet. Set the compass needle swinging and then allow it to

come to rest. Observe that the needle arranges itself with its marked end pointing towards the unmarked end of the magnet. The reverse is true of the other pole of the needle. We say the magnet exerts a *directive* force upon the needle. Put the needle in other positions on the magnet and notice same thing.

We are able to understand from this experiment why a compass needle always arranges itself with its marked end towards the north. It is because the earth acts like the bar-magnet. That part of the earth in the northern hemisphere acts like the unmarked or south-seeking end of the magnet, and attracts the marked end of the needle. That place where this attractive force is greatest is called the *north magnetic pole*, and though at first it seems contradictory, there must be the south-seeking kind of magnetism at the north magnetic pole. The line in which the needle arranges itself is called the *magnetic meridian.*

The North Geographical Pole and the North Magnetic Pole do not Coincide.—The consequence of this is that the geographical meridians (p. 156) and the magnetic meridians also do not coincide. The angle they make with one another is different in different places. It is called the *angle of declination.* Its value at Greenwich for 1896 is 17° West of North (Fig. 158). Knowing this, we are always able to find the geographical meridian.

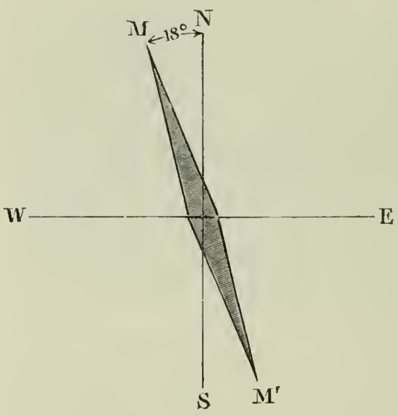

FIG. 158.—The Angle of Declination. NS is the Geographical Meridian.

How to find the Geographical Meridian.—

EXPT. 215.—Allow a freely-suspended compass needle to come to rest. Draw a line on the table marking out the direction of the needle. Through the point under the spot where the needle is supported draw a line inclined to the *magnetic meridian* you have just drawn, at an angle

equal to the magnetic declination of the place, which is marked on many geographical charts. The line thus obtained is the geographical meridian.

Dip.—

Expt. 216.—Magnetise a sewing needle as in Expt. 209. Suspend it by a thread so that it hangs quite horizontally. Bring it over the neutral line of a bar-magnet and notice that it remains horizontal. Gradually move it towards the north-seeking end of the magnet. Observe that as the pole of the magnet is approached the south-seeking end of the needle becomes inclined at larger and larger angles to the bar-magnet, until when it is over the end it is vertical. The angle which the needle makes with the bar-magnet corresponds to the *angle of dip of a dipping needle.*

The Dipping Needle is simply a magnetic needle suspended in such a manner that it is free to move in a vertical plane after the plan of Expt. 216. Fig. 159 will make its construction quite clear. The angle which the needle makes in any place is read off a carefully graduated circle round which the needle moves. The needle dips because, as has been already stated, the earth acts like a magnet. As one would expect, at some places on the earth's surface the dipping needle is quite horizontal. There is no dip. A line connecting all places where this is true, is the magnetic equator of the earth, and corresponds to the neutral line of the bar-magnet. Just as the needle in the last experiment stood vertically over the poles of the bar-magnet, so the dipping needle will be at an angle of 90° over the north or south magnetic poles of the earth. This enables the earth's magnetic poles to be found. The north magnetic pole of the earth is situated in Boothia Felix, Lat. 70° 5′ N., Long. 96° 46′, and is about 1,000 miles distant from the true north pole. The student will at once understand that it is the north-seeking pole of the dipping needle which dips in the

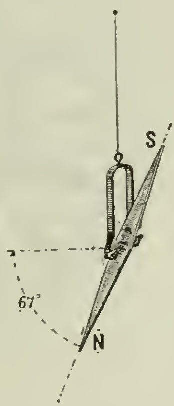

Fig. 159.—A Dipping Needle.

northern hemisphere, because it is the same south-seeking magnetism which makes it point to the north as causes it to dip. The value of the angle of dip in London in 1896 is $67\frac{1}{4}°$.

The Earth as a Magnet.—The various phenomena, which we have only been able to briefly refer to, would all happen in precisely the same way if passing through the earth there were a huge bar-magnet arranged along a diameter with its south-seeking pole under the north magnetic pole. The position

FIG. 160.—The Mariner's Compass.

given by the dipping needle is exactly that which such a bar-magnet would make it take up. The neutral line of the bar-magnet would be the position of the magnetic equator of the earth, and the magnetic poles of the earth would be over those of the magnet. Of course, we know very well that no such gigantic magnet is hidden away in the earth's interior, but the illustration affords a ready means of remembering the chief points which have been enumerated.

The Mariner's Compass.—Expt. 210 has shown that every suitably supported magnet arranges itself in the magnetic meridian, and it is on this fact that the mariner's compass depends for its construction. In the actual instrument, a flat needle is suspended by means of an agate cap, placed at its centre of gravity. The cap works on a point in such a manner that the needle can move freely in a horizontal plane. On the top of the needle a card, divided as shown in Fig. 160, is fixed, care being taken that the centre of the needle is under the centre of the card, and the north-seeking pole of the magnet under the division marked north on the card. This north point is indicated in the figure by means of the *fleur-de-lis*. With this arrangement the direction of the magnetic north pole is always seen by looking at the *fleur-de-lis*. The dotted line indicates the direction of the middle line, from bow to stern, of the ship upon which the compass-card in the figure is supposed to be. When the man at the helm wishes the ship to travel in any particular direction, he turns the wheel until the required point of the compass comes under the arrow on the dotted line. In Fig. 160 the compass-card indicates that the ship, the medial line of which is shown, is travelling in a N.N.E. direction.

Chief Points of Chapter XXI.

Lodestone is a natural binary compound of iron and oxygen which possesses the property (1) of attracting iron and steel filings; (2) of coming to rest in a *magnetic* north and south line when freely suspended or balanced.

Artificial Magnets have the same properties as lodestone; they can be made (1) by stroking a piece of steel in one direction with a lodestone or with a magnet; (2) by coiling a silk-covered wire around a piece of steel and passing a current of electricity through it.

The Primary Law of magnetic attraction and repulsion is, like poles repel one another; unlike poles attract one another.

Magnetic Declination or Variation is the angle between a true north and south line (shown by a noonday shadow) and a magnetic north and south line (shown by a compass needle). It differs at different places.

Magnetic Dip or Inclination is the angle which a magnetic needle turning about a horizontal axis makes with the horizon when the vertical plane in which it moves coincides with the magnetic meridian.

The Earth's Magnetic Poles are the points through which magnetic meridians pass, and at which a dipping needle would set vertically. The north magnetic pole is in Boothia Felix, but the south magnetic pole has not been reached.

Questions on Chapter XXI.

(1) What is the "dip" of a magnetic needle? Why is it greatest at the magnetic poles? (1896.)

(2) Describe the mariner's compass and its chief uses. (1895.)

(3) How would you set out a north and south line—

(*a*) By the mariner's compass?

(*b*) By the sun?

(*c*) By a star?

(4) What are the primary laws of magnetic attraction and repulsion?

(5) Describe the behaviour of a compass needle and a dip needle at the magnetic equator and magnetic poles.

(6) A knitting needle is accurately balanced at its centre and then magnetised. Show, by means of diagrams, how the needle would come to rest if placed—(*a*) in the magnetic meridian; (*b*) at right angles to the meridian.

Questions set at the Cambridge Local Examinations.

The following questions, from papers set at the Cambridge Local Examinations in Physical Geography, bear upon the subjects of most of the chapters in this book, and afford useful exercises for the student. S.C. signifies Senior Cambridge, J.C. Junior Cambridge.

1. Explain clearly why the heating power of the sun's rays is great at noon and comparatively feeble in the morning and evening. (S. C. 1886.)

2. Illustrate, by examples derived from the British coast, the action of the sea in destroying land by denudation. (S. C. 1886.)

3. Describe the system of oceanic currents of the Atlantic Ocean. Discuss the mode of production of such currents. (S. C. 1886.)

4. A volcano has been named a "hill of accumulation." Show by describing the structure of any volcano that this title is appropriate. (S. C. 1886.)

5. On the south side of the Khasia Hills (N. of the Bay of Bengal) the rainfall is enormous, whilst on the north side of the same it is much less. Explain the reasons for this. (S. C. 1885.)

6. Above Niagara Falls the river flows in a wide shallow valley, whilst below them it runs in a deep narrow gorge. How do you account for this? Give reasons for your answer. (S. C. 1885.)

7. Rivers bring down stones, sand, clay in suspension, and lime in solution. How are these various materials deposited on the ocean floors? (S. C. 1885.)

8. In the country round Snowdon, the rocks in the lower parts of the valleys are polished and scratched, and present rounded outlines, whilst in the higher ridges they are rough and angular. How do you account for these phenomena? (S. C. 1885.)

9. What is an isothermal line? Mention some of the chief causes which make these lines deviate widely from the lines of latitude. (S. C. 1885.)

10. What is meant by the *snow-line* of a country? Explain how snow is got rid of in a region where the snow-line remains below the principal mountain summits throughout the year. (S. C. 1887.)

11. How are peat-mosses formed?

Account for their general absence in tropical regions. (S. C. 1887.)

12. Show clearly in what ways cold and warm ocean currents influence climate.

In what manner would the depression of Behring Strait be likely to affect the climate of North America and the Arctic Regions? (S. C. 1888.)

13. Mention two volcanic regions which are subject to earthquakes and also to slow elevation or subsidence of the land.

What are the motive powers of volcanoes and earthquakes? (S. C. 1888.)

14. State and account for the variations in temperature met with on ascending into the air and descending into the earth and sea. (S. C. 1889.)

15. Explain clearly why the days and nights are not of equal length throughout the year. What is the cause of the regular succession of the seasons? (J. C. 1890.)

16. What is meant by the "pressure of the atmosphere"? Explain the effect of (1) heat, (2) aqueous vapour, on atmospheric pressure. (J. C. 1890.)

17. How is the condensation of aqueous vapour in the atmosphere brought about?

Account for the rainfall being greater in the western than in the eastern part of Britain. (J. C. 1890.)

18. Describe briefly the course of the Gulf Stream. How are ocean currents produced? (J. C. 1890.)

19. Describe the mode of origin of icebergs.

Give an account of the work performed by a glacier. (J. C. 1890.)

20. Give a short account of the different kinds of springs, illustrating your answer with diagrams. (J. C. 1890.)

21. Describe the products of a volcanic eruption and give the distribution of active volcanoes. (J. C. 1890.)

22. The two chief movements of the earth are called Rotation and Revolution. Explain these terms. "When the North Pole is enjoying perpetual daylight, the South Pole must be in continuous night." Account for this. (J. C. 1890.)

23. Explain clearly the manner in which the atmosphere is heated. (J. C. 1890.)

24. State the causes which may give rise to an excessive rainfall in a district; and give some examples.

Why are the south-west winds in Britain usually accompanied by rain, while east winds generally bring dry weather? (J. C. 1890.)

25. What is meant by a snow-line? On what conditions does the height of the snow-line on different mountains depend? (J. C. 1890.)

26. Describe the structure and mode of formation of a volcanic cone. (J. C. 1890.)

27. How does the water of mineral springs differ from rain-water? Describe briefly the mode of origin of inland caves. (J. C. 1890.)

28. Explain how the temperature of the air is regulated by (i) latitude; (ii) distribution of land and sea; (iii) altitude. (S. C. 1890.)

29. Give some account of the features which would induce you to believe that a tract of country had undergone upheaval in recent times, and mention a case of the occurrence of such an upward movement. (S. C. 1890.)

30. What are the principal causes of the variations in the pressure of the air at any one place, and why do they produce such variations? (S. C. 1890.)

31. Give an account of the geographical distribution, direction, and causes of the trade winds. (S. C. 1890.)

32. Draw a rough map of the north Atlantic Ocean, showing the distribution and directions of the surface currents, and distinguish between warm and cold currents. (S. C. 1890.)

33. Describe and account for the circulation of water from sea to atmosphere, from atmosphere to earth, from earth to sea. (S. C. 1891.)

34. What part does the sea play as (i) a receptacle of sediment; (ii) an agent of denudation; and (iii) a carrier of heat? (S. C. 1891.)

35. Explain clearly how springs are caused. With what mineral substances are spring-waters frequently charged, and from what source are these derived? (S. C. 1891.)

36. How do you account for the production of waterfalls? What evidence is furnished by the district round Falls of Niagara as to the manner in which those falls were produced? (S. C. 1891.)

37. Give some account of the nature and composition of the materials which are emitted from volcanic orifices. (S. C. 1891.)

38. How can you prove that the earth is approximately spherical? (J. C. 1891.)

39. What are isothermal lines? Places which lie on the same parallels of latitude frequently do not possess the same mean annual temperature. Explain clearly the reasons for this, giving instances. (J. C. 1891.)

40. What are the trade-winds? State the causes to which they are due. (J. C. 1891.)

41. What reasons are there for believing that a high temperature exists in the interior of the earth? (J. C. 1891.)

42. Give what evidence you can to prove that some parts of the surface of the earth have been upheaved in recent times. (J. C. 1891.)

43. What do you understand by the following terms:—equator, solstice, meridian of Greenwich, equinox? (J. C. 1891.)

44. Explain clearly the manner in which land-breezes and sea-breezes are produced. What are cyclones and anti-cyclones? (J. C. 1891)

45. How has it been proved that some parts of the earth's surface have been depressed in recent times? (J. C. 1891.)

46. State what you know of the composition of sea-water. (J. C. 1891.)

47. Describe briefly the mode of formation of a river valley. (J. C. 1891.)

48. Explain the terms: ecliptic, zenith, greater circle.

Why does not a 10lb. weight fall to the ground ten times as fast as a 1lb. weight. (J. C. 1892.)

49. State what you know about the distribution of the rainfall of England and Wales. (J. C. 1892.)

50. Describe a mercurial barometer. What is observed when a barometer is taken up to the top of a high mountain?

Explain the terms *isobar* and *isotherm*. (J. C. 1892.)

51. Explain the terms:—latitude, orbit, zodiac.

If the sun attracts the earth, why does not the earth fall into the sun? (J. C. 1892.)

52. Explain how the atmosphere is warmed. Why is it that on going up in a balloon we find that the higher we ascend the colder is the air? (J. C. 1892.)

53. Explain why certain inland lakes are salt, while others are fresh. Give instances of both. (J. C. 1892.)

54. Describe the structure and appearance of a glacier. (J. C. 1892.)

55. Give some account (with examples) of the different kinds of coral reefs. (J. C. 1892.)

56. What are *monsoons*? Why does a south-west monsoon blow in the Indian Ocean north of the equator from April to October, and a north-east monsoon in the same area from October to April? (S. C. 1892.)

57. Explain clearly how we are able to reckon time by periods of (i) years; (ii) lunar months; (iii) days. (S. C. 1892.)

58. Write a short account of the work done by rain and rivers in forming a river-valley (i) in hard-rocks; (ii) in soft rocks. (S. C. 1892.)

59. Give an account of the work performed by glaciers. What is an ice-sheet? (S. C. 1892.)

60. Explain the terms:—longitude, tropic, solar system.

Draw diagrams showing how the earth's revolution round the sun causes the seasons. (J. C. 1893.)

61. Explain the differences between a mercurial barometer and a mercurial thermometer, and state for what purpose each instrument is used.

What is meant by the expression corrected to sea-level and reduced to 32° F.? (J. C. 1893.)

62. Distinguish between a mineral and a rock. Describe three common rocks and explain their origin. (J. C. 1893.)

63. Explain the terms: zone, planet, solstice; show by means of diagrams why the length of the day differs at different times of the year. (J. C. 1893.)

64. Of what gases is the atmosphere composed?

How do animals and green plants respectively affect the composition of the air? (J. C. 1893.)

65. State what you know about the following: atoll, iceberg, lava, stalactite, globigerina ooze. (J. C. 1893.)

66. What is a delta and how is it formed? What materials are carried by rivers in solution, and what becomes of them when the rivers enter the sea? (J. C. 1893.)

67. Mention some examples of geysers and hot springs. Whence do they derive their heat? (J. C. 1893.)

68. Describe the formation of dew and fog. Explain the prevalence of fogs—(*a*) off the coast of Nova Scotia; (*b*) in London. (S. C. 1893.)

69. Describe the mode of formation of cloud and rain. Give an example of a very rainy and of a very dry district, and explain the causes of the difference. (S. C. 1893.)

70. Explain the terms: eclipse, ecliptic, arctic circle. (J. C. 1894.)

71. When it is noon at Greenwich, what time is it in Calcutta (nearly 90° E. long.); in New Orleans (90° W. long); and in New Caledonia (165° E. long.)? (J. C. 1894.)

72. Give some account of the origin of chalk. (J. C. 1894.)

73. Explain terms: isobar, monsoon, roaring forties. (J. C. 1894.)

74. Why are caverns common in many limestone districts? Give examples. (J. C. 1894.)

75. What do you understand by alluvium, pot-hole, gorge? (J. C. 1894.)

76. Explain the terms: (i) horizon; (ii) meridian; (iii) antarctic circle. (J. C. 1894.)

77. What is meant by the terms *nadir* and *zenith*? At what part of the earth would an observer see the pole-star in his zenith? (J. C. 1894.)

78. Name and describe three rocks of organic origin. (J. C. 1894.)

79. Explain the terms: (i) Roche moutonnée; (ii) erratic block; (iii) moraine. (J. C. 1894.)

80. What do you understand by the terms: (i) escarpment; (ii) watershed; (iii) delta? (J. C. 1894.)

81. Explain the terms: earth's axis, meridians of longitude. (J. C. 1895.)

82. Distinguish between the earth's rotation and its revolution. Which of these causes the alternation of day and night and how? (J. C. 1895.)

83. Describe the composition of the atmosphere. (J. C. 1895.)

84. Account for the production of "land-breezes" and "sea-breezes." (J. C. 1895.)

85. Explain why a surface current flows outward from the Baltic into the open ocean and another flows inward from the open ocean to the Mediterranean. (J. C. 1895.)

86. What are surface springs and what conditions are necessary for their existence? (J. C. 1895.)

87. Explain what is meant by each of the following terms: moraine, snow-line, prairie. (J. C. 1895.)

88. Describe any noteworthy feature in connection with the following, Dead Sea, Khasia Hills, River Nile. (J. C. 1895.)

89. Give an account of the general structure of a volcano and of its mode of formation. (J. C. 1895.)

INDEX

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